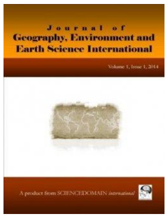

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Structural Analysis Using Upwards Continuation / Lineaments Trends Analysis on Aeromagnetic Data: A Case Study of Southern Nigeria Basins

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Authors' contributions

This work was carried out in collaboration between both authors. DAO acquired all the data and processed all the manual data and its interpretations, he also took part in running the computer processed analysis and in writing the paper. Author AMG provided the computer software's and processed the computer based analysis; he also edited the written paper. Both authors read and approved the final manuscript.

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ABSTRACT

Twenty aeromagnetic maps were used for this study, which covers parts of Southern Sedimentary basins and their adjourning basement flanks in Nigeria. The aeromagnetic maps were acquired from the Nigeria Geological Survey Agency on a scale of 1: 100,000. The data was digitized manually along flight lines and a total of 16,689 data points obtained. The information was processed using computer techniques such as map merging, reduction to pole, polynomial filtering, upwards continuation, manual trend analysis and depth estimates. The results from upwards continuation reveals five major deep-seated anomalous fracture trends which could characterize major depositional centers. Lineaments trend results indicate dominant NE –SW trends within the Niger Delta, Mamfe basin, Lower Benue Trough, and Anambra basins, while the Calabar Flank

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area has a NW –SE Lineaments trends. Manual depth estimates indicate grater sediments thickness within the deeply seated anomalies ranging between 2.5km -10.0km, and within the shallow anomalous structures depth to source of anomalies varies between 1.0km – 2.0 km .The identified five major deep-seated anomalies characterize good prospecting sites for possible hydrocarbon deposits accumulation.

Keywords: Reduction-pole; polynomial filtering; upwards continuation; lineaments, hydrocarbon.

1. INTRODUCTION

The study area covers parts of five sedimentary basins in Nigeria; this includes the Calabar Flank, Niger Delta, Mamfe basin, Anambra basin and Lower Benue Trough. The area is located within longitude $7^{\circ}0$ ' 00 '' – $9^{\circ}0$ ' 00 '' E and latitude $4^{\circ}0$ ' 00 '' - $7^{\circ}0$ ' 00 '' N .These basins cover known hydrocarbon producing basin (Niger Delta and Anambra) and that basin where hydrocarbon deposit are relatively unknown Mamfe and Lower Benue Trough). Though the structural orientations of these areas has been reported on local scales, this study seeks to study these structural orientation and depth variations on a regional scale. Scholar who has worked on aeromagnetic data on local scales reported varying depth values and lineament trend direction. [1,2,3,4]. This study is on a regional scale covering the covering the entire southern Nigeria basins aimed at revealing the subsurface structural fracture trends that characterize sedimentation processes within these basins. Lineaments patterns from known established fracture zones (chain and charcort) around the marginal Niger delta basin would be identified and compared to similar fracture patterns within the inland basins in detecting possible hydrocarbon exploration sites.

1.1 Geology

The study area (Fig.1) has different geological histories given that it has both marginal and inland basins. The opening of the Atlantic Ocean separated the African plate from the South American plate which resulted to a failed Cretaceous rift system that opened up the Benue Trough in Nigeria [5,6,7]. Cretaceous transgressive and regressive episodes marked the early sedimentation patterns in the then Lower Benue Trough now termed the Calabar Flank had the first marine incursion through deep fracture zones the chain and charcort faults system [6,8,9]. This was followed by several tectonic episodes accompanied by several events of transgressive and regressive cycles depositing different formations and subsequent formation of younger basins of the Lower Benue Trough, Mamfe basin, Ananmbra basin and the youngest tertiary Niger Delta basin.

The Calabar Flank Sedimentary basin has the Cretaceous Awi Formation sitting directly on the '' Oban Massif '' basement rocks which consist of mainly Gniesses, Granites, and Schist.The Awi Formation consists of Albian Sandstones, overlain by cenomanian – maastrichtian formations of Mfamosing Limestones, Ekenkpong shales, New Netin Marls, Nkporo Shales and overlain by the Tertiary Benin Formation Sandstones as the topmost unit of the calabar flank basin [10]. The Eze-Aku formation within the Mamfe basin are sitting directly on the ''Afi'' basement massif and parts of the Oban basement massif and consist of Shale and Sandstones, this formation is overlain by the Agwu Formation mainly shales and minor sandstones which is overlain by the Nkporo Shales. The Anambra basin has formations from late Cretaceous – early Teriary which include Agwu, Imo Shale, and Ameke [7]. The Anambra basin transformational processes gave rise to the present day Niger Delta deposits. The Niger Delta has three major lithostratigraphic units the AKata Formation, mainly shales, the Agbada Formation made of sanstones and Shales in almost equal proportions and the Benin Formation made of Tertiary coastal plain Sandstones [6,11,12,13].

2. THEORETICAL BACKGROUND

2.1 Upwards Continuation

This is the process of transforming potential field data measured on one surface to some other higher surface [11,1,14]. It is used as a filter to reduce the effect of near-surface bodies in other to emphasize anomalies from deep features. Since the data are being ''moved'' away from the source,

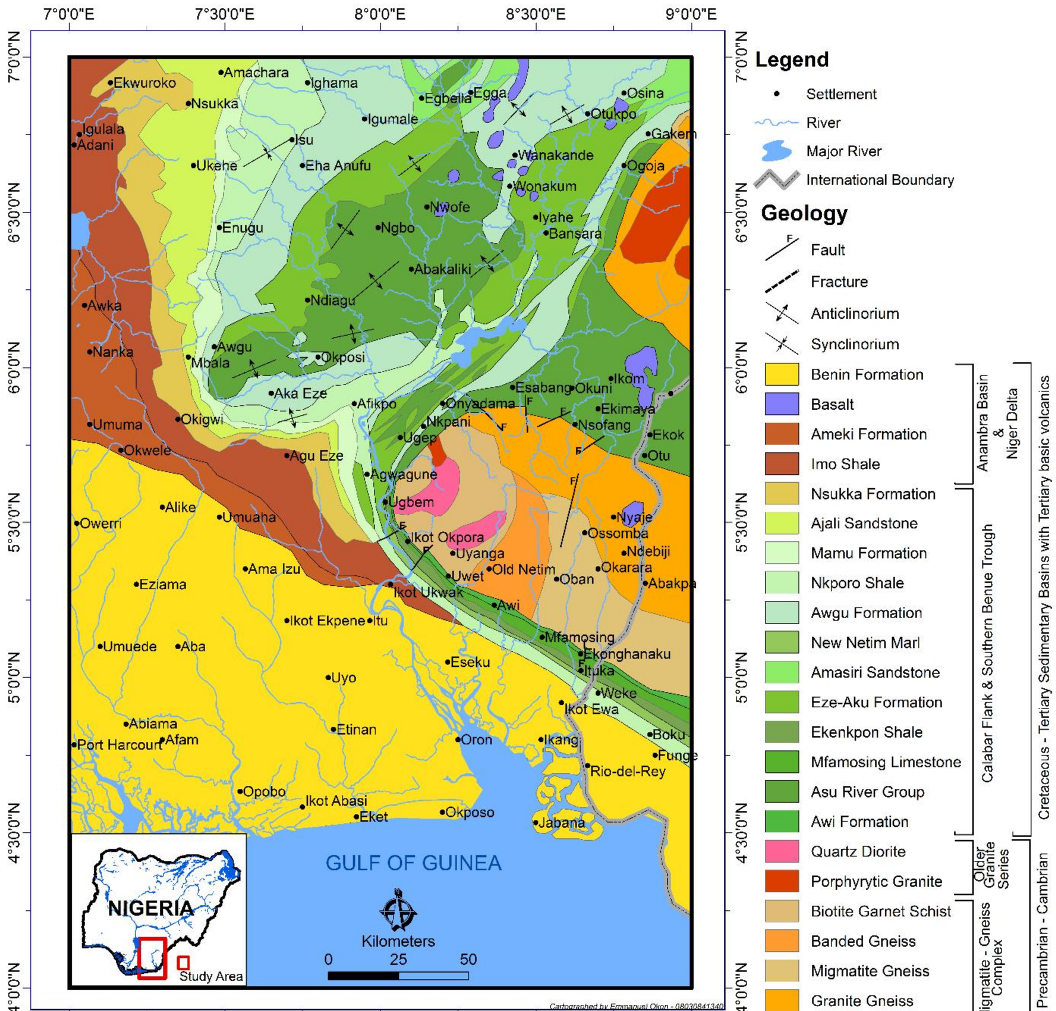

Fig. 1. Geologic sketch map of the study area , based on map by Nigeria Geologic Survey Agency (1994)

This procedure is generally stable mathematically using Fourier domain algorithms by applying inverse Fourier transforms carried out in the Fourier domain.

$$Tuc^{(u,v)} = e^{\Delta\ z/k/} \text{ ....(1)}$$

$$\text{Where } /k/= (u^2 + v^2) \text{ .... (2)}$$

And u and v represent x and y wave numbers and z is the continuation height. These operations are carried out in the space domain.

2.2 Lineaments Trends

The computation of lineament trends manually involves spreading all the sheets on a desk (table) and starting with a single sheet an overlay transparency is laid on the aeromagnetic sheet and all the major anomalies traced on the overlay.The following parameters are deduced from each of the traced anomalies (i) Length of anomalies (ii) Orientation of anomalies in degrees (iii)Maximum closure of anomalies in gammas [15]. The above parameters were extracted for all anomalies from where percentage frequency analysis of all major lineaments were computed . The computation was done grouping the frequency of occurrence of the orientations of these anomalies, their total lengths and the percentage of the normalized lengths used to plot rose diagrams which specifies the orientations of major anomalies in the different sub-basins of the study area.

2.3 Depth to Magnetic Source

Manually analysed depth to magnetic sources were done along chosen profiles cutting across prominent anomalies , the maximum slope technique was employed. The process involves taking a tangent at the flexing point of the dyke contact model type [16]. Seven lines were chosen and plots of distance against total magnetic field intensity generated using excel software , once the flexure curve points are inserted the depth to magnetic sources are read along the distance axis to represent the estimated depth of the studied basin.

2.4 Data Analysis

The materials used for this analysis include the following (i) Twenty aeromagnetic maps (ii) Geological map of Nigeria (iii) United States Geological Services potential field software version 2.2 (iv) Surfer 9.0 and Excell softwares (v) Tracing papers ,mathematical set, desk table. The analysis was done using both manual and computer processed techniques, all the aeromagnetic maps were spread out and manual digitization done on each of the sheets along flight lines.The process of extracting x, y and z which represents longitude, latitude and observed total magnetic field was performed at each marked point along flight lines, this procedure followed the specification of the U.S.G.S standard format for the software [17,18]. A total of 16,689 data points were obtained from the digitized and stored as a file for further processing , surfer 9.0 software was used to contour and merge all the data producing the Observed Total Magnetic Field Intensity colored map (Fig.2). The U.S.G.S software which had suites of packages (A2XYZ, DETOUR, P2GRD, GEOCON, ADDGRD, JMERGER, MINC, PC-CONTOUR,) was used in map merging all the maps to produce the Observed Total Magnetic Field Intensity map, further processing was done to separate the regional and residual fields using another suites of U.S.G.S software (SURFIT, FFTFIL, PREP-5 ,FR_TP, DE-PREP5) to produce the residual and reduced – pole-magnetic fields (Fig.3). Also

Upwards continuation was applied using the filtering program with different sub- routines (CK_DIMS, PLUGGRID, PREP5, DE-PREP5, FFTFIL) which runs through command files (UPCONT) to process a band pass filtering and upwards continues the data at 1.0 km, 2.0 km, and 5.0 km respectively. These upward continued data stored as different files are further contoured using another software program ‘’PC-CONTOUR’’ to produce the upwards continuation maps (Fig.4.0, 5.0 and 6.0) . Depth to magnetic source of anomalies was performed from five lines selected that cuts across prominent anomalies within the study area. The maximum slope method was employed in computing depths to magnetic anomaly. Profile A ran across the Niger Delta towards the Calabar Flank (Fig. 7). The Calabar area had depths which varies between 1.75 km – 3.0 km , Uwet 2.5 km, Opobo 6.5 km – 7.0 km , and Bonny 8.0 km -10.0 km . Also, four profile lines cuts across Ogoja, Ikom, Bansara and Afikpo areas (Fig. 8,9,10,11) representing the Lower Benue Trough, Mamfe basin and Parts of Anambra basin. Manual depth estimates within these profiles indicate that the Ogoja area has depth ranging between 2.5km -3.2 km , Ikom area 1.5 km -2.0 km , Bansara area 3.0 km 3.4 km, and the Afikpo area 2.0 km -2.2 km (Table 1.0) . Also, frequency analysis was performed in six selected map sheets (Ikom, Bansara, Ogoja, Afikpo, Calabar, and Port-Harcourt) . The Ikom area (Mamfe basin) has a dominant NE-SW anomalous trends with a dominant normalized length of 24% which range between 81^0 - 90^0 and 261^0 - 270^0 (Fig. 13, table 2.0). The Ogoja area has dominantly NE – SW trend with a normalized length of 20.2% ranging between 51^0 - 60^0 and 231^0 - 240^0 (Fig14. Table 3.0).The Afikpo area has a dominant NE – SW trend with a normalized length of 35.2% which range between 51^0 - 60^0 and 241° - 260° (Fig.15 , table 4.0). The Calabar area has a dominant NW – SE trend with a normalized anomaly length 42.5% ranging between 102^0 - 172° and 274° – 295° (Fig.16 table 5.0). While. The Bonny area has a dominant NE – SW trend with a dominant normalized anomalies length of 51.2% ranging from 47° -71° and 250° - 265° (Fig.17, table 6.0).

3. DISCUSSION OF RESULTS

The merged total magnetic field intensity map (Fig.2) has two prominent anomalies marked as FFF which represent ancient suture zones of chain and fracture fracture zones [14,8]. The reduced to pole magnetic map (Fig.3) indicate centered residual anomalies prior to the application of upwards continuation which emphasized deep seated anomalies (Figs.4,5, 6).

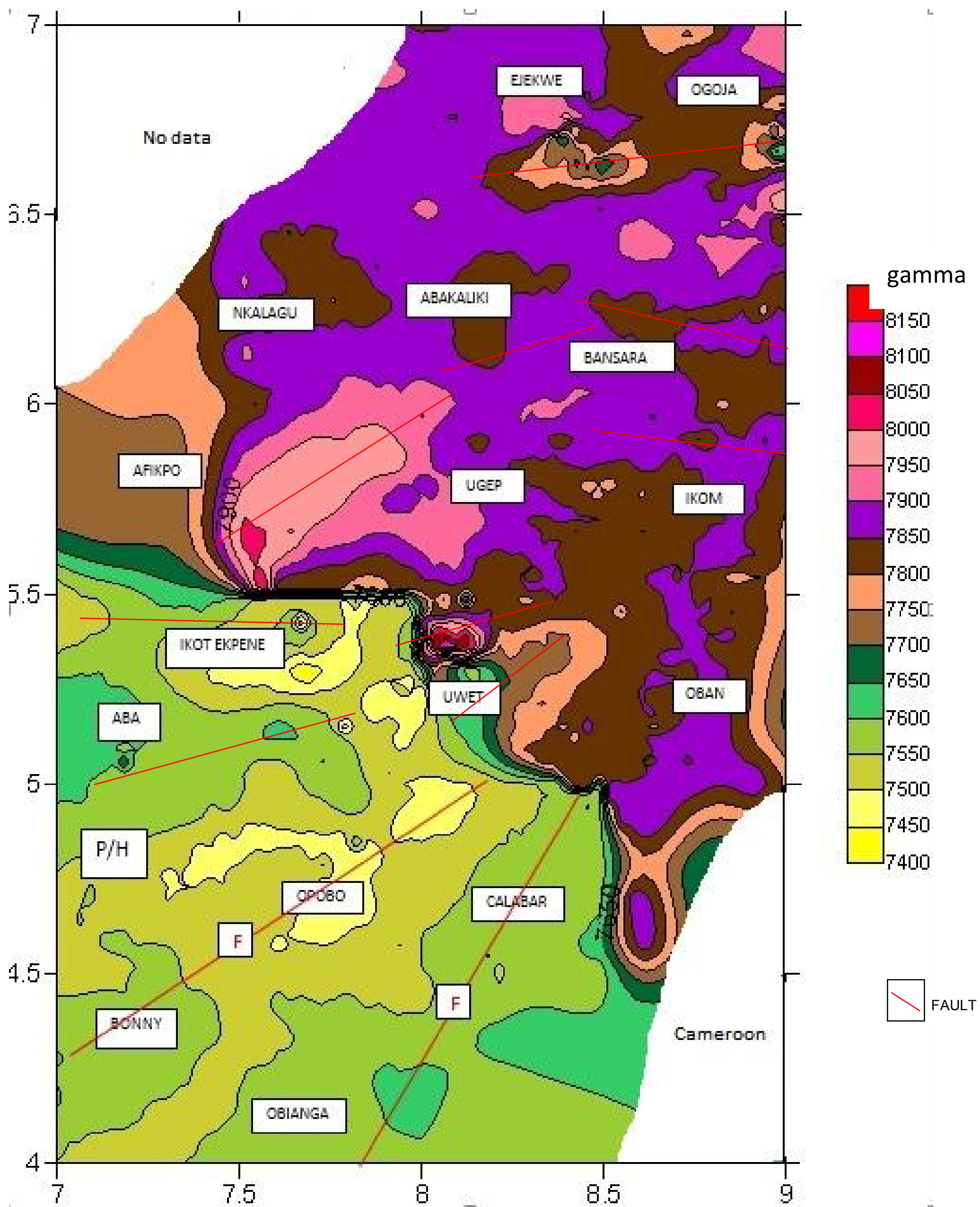

Fig. 2. Merged coloured total magnetic field intensity map of the study area.(contoured at 50nT)

upwards continuation acts as a filtering technique so, when applied at 1.0 km nineteen major anomalies indicating seven deep seated and twelve shallow seated were identified (Fig.4). The deep seated anomalies were characterized by widely spaced elliptical anomalies which were mainly found around Port-Harcourt, Aba, Ikot-Ekpene, Obianga, (Niger Delta) and Bansara (Mamfe basin) areas.The shallow seated anomalies were characterized by tight circular or spherical anomalies found around Oban, Uwet, Ugep, Nkalagu, Ikom . Futher continuation to heighs of 2.0 km filtered the data and the total number of anomalies reduced to thirteen (five deep seated and eight shallow seated (Fig.5), the deep seated anomalies where found around the Niger Delta towns while the shallow seated ones where found around the Calabar Flank and

Lower Benue towns. The data when moved to continuation heights of 5.0 km filtered all the shallow seated anomalies leaving only five deep seated anomalies (Fig.6).

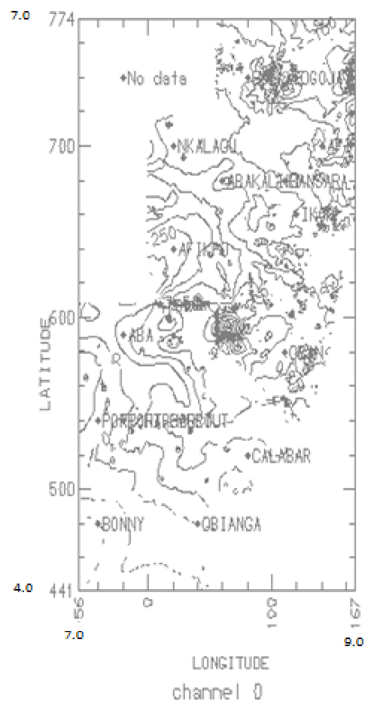

Fig. 3. Reduced to pole polynomial residual map of the study area (contoured at 50nT)

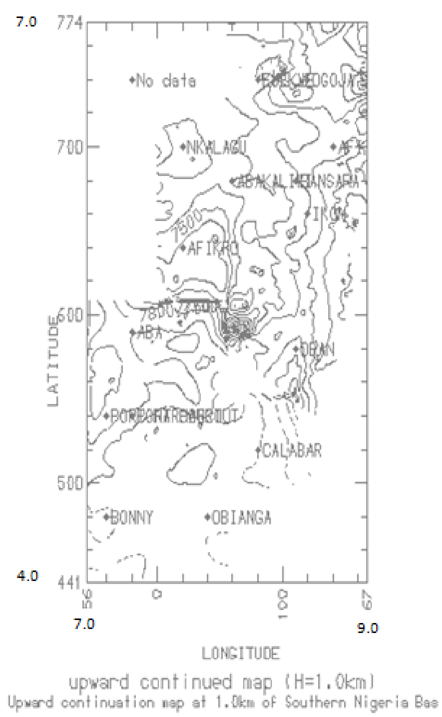

Fig. 4. Upward continuation map of the study area at 1.0 km

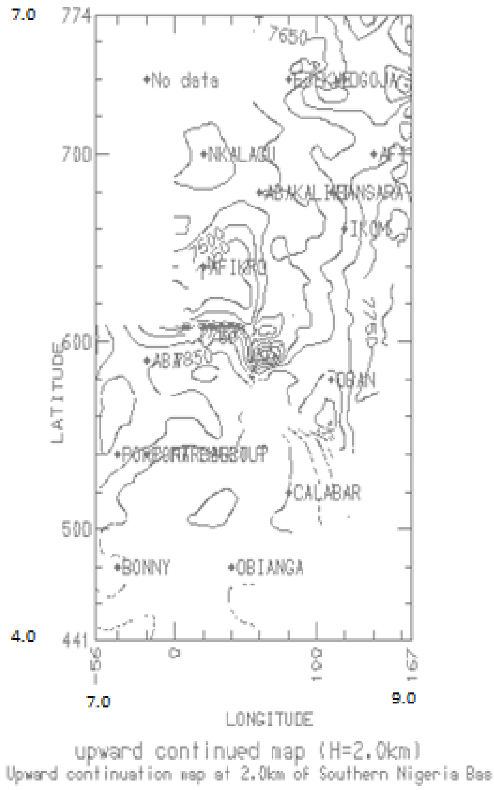

Fig. 5. Upward continution map of the study area at 2.0 km

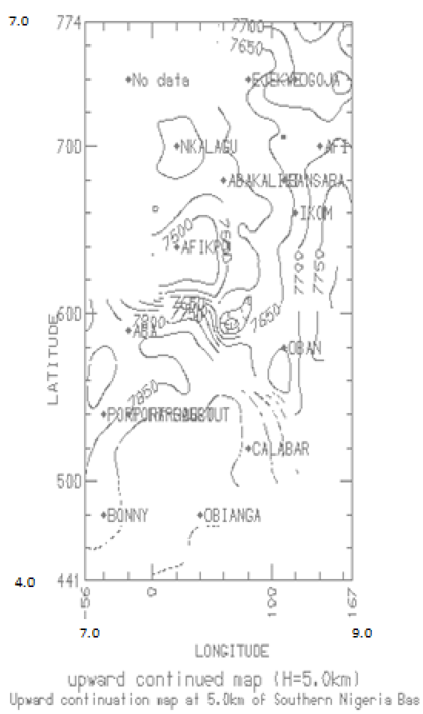

Fig. 6. Upwards continuation map of the study area at 5.0 km

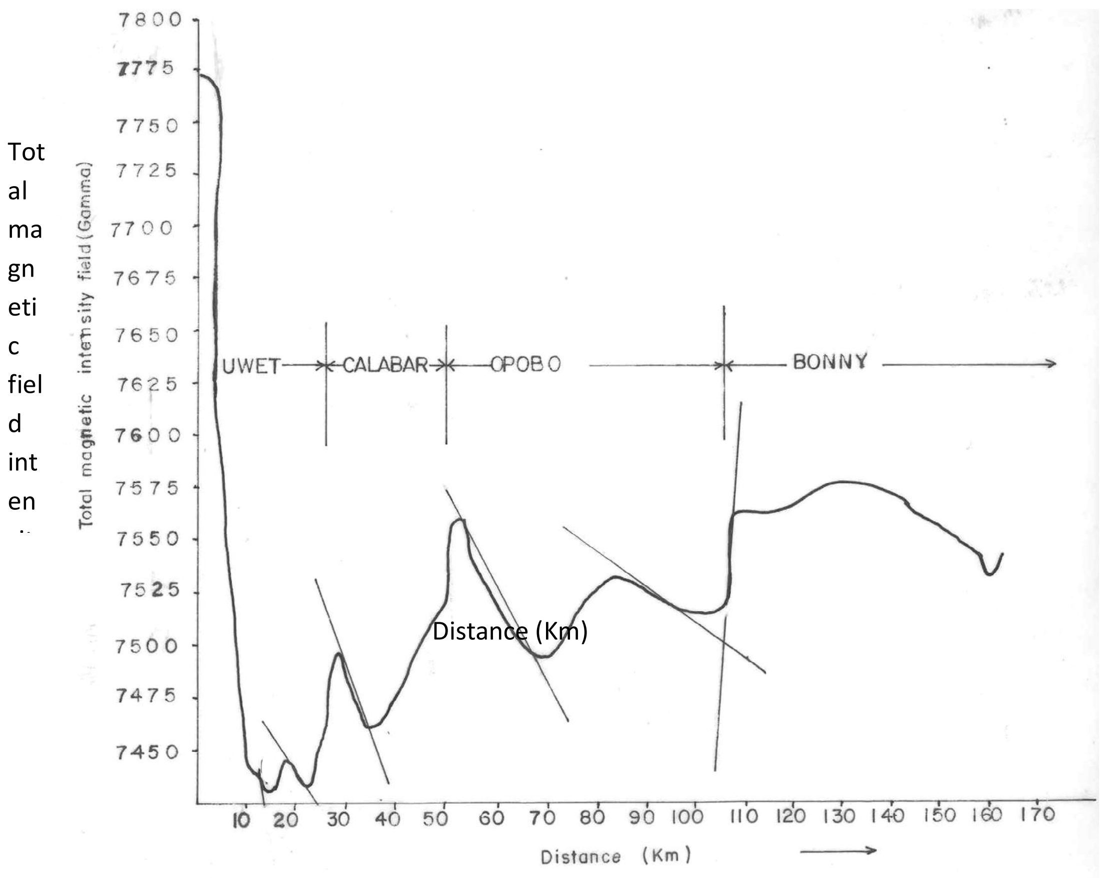

Fig. 7. Total magnetic field intensity profile from Uwet to Calabar, Opobo and Bonny showing locations of manual depth computed areas

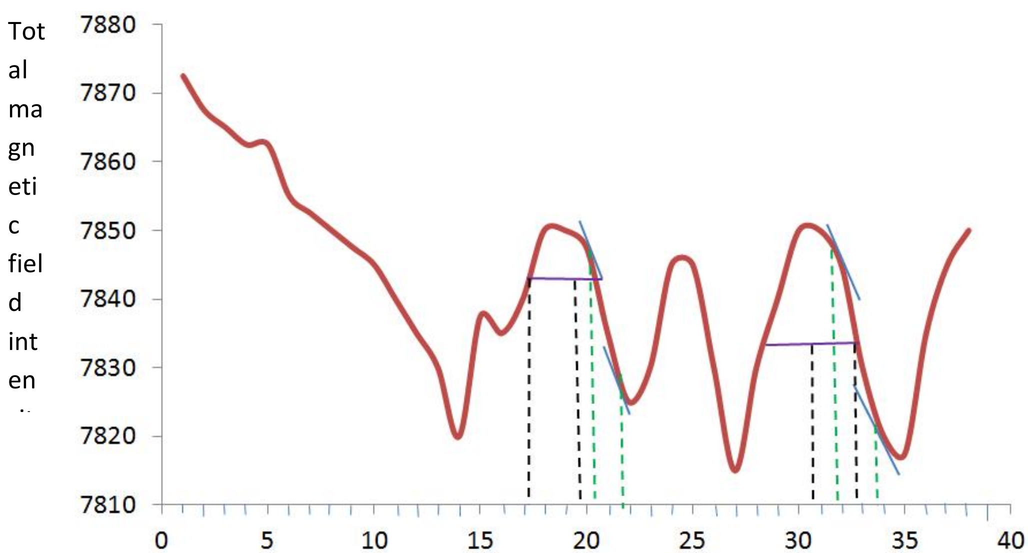

Fig. 8. Total magnetic field profile along ogoja showing locations of manual depth computed areas

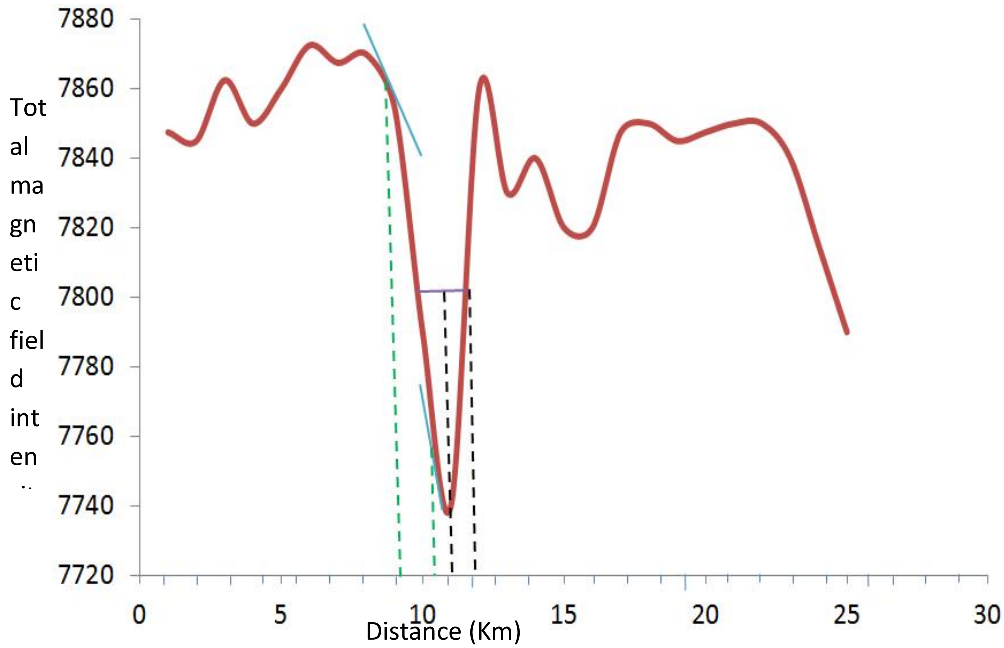

Fig. 9. Total magnetic field profile along Ikom showing locations of manual depth computed areas

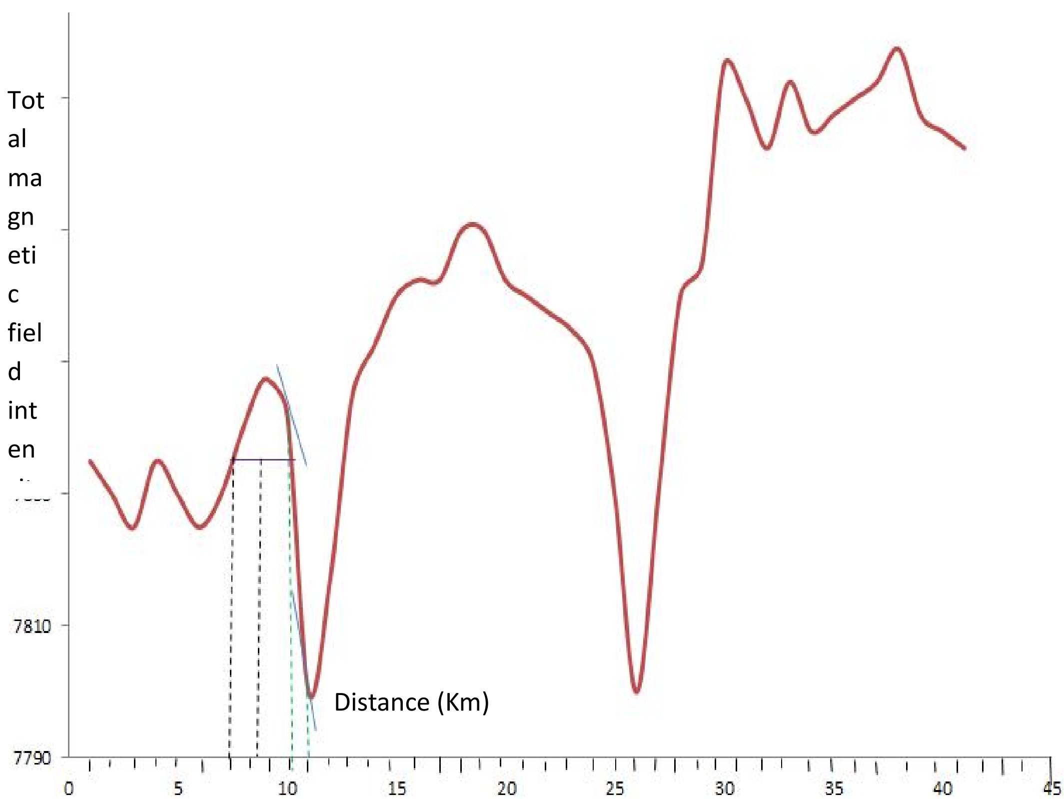

Fig. 10. Total magnetic field profile along Bansara showing locations of manual depth computed areas

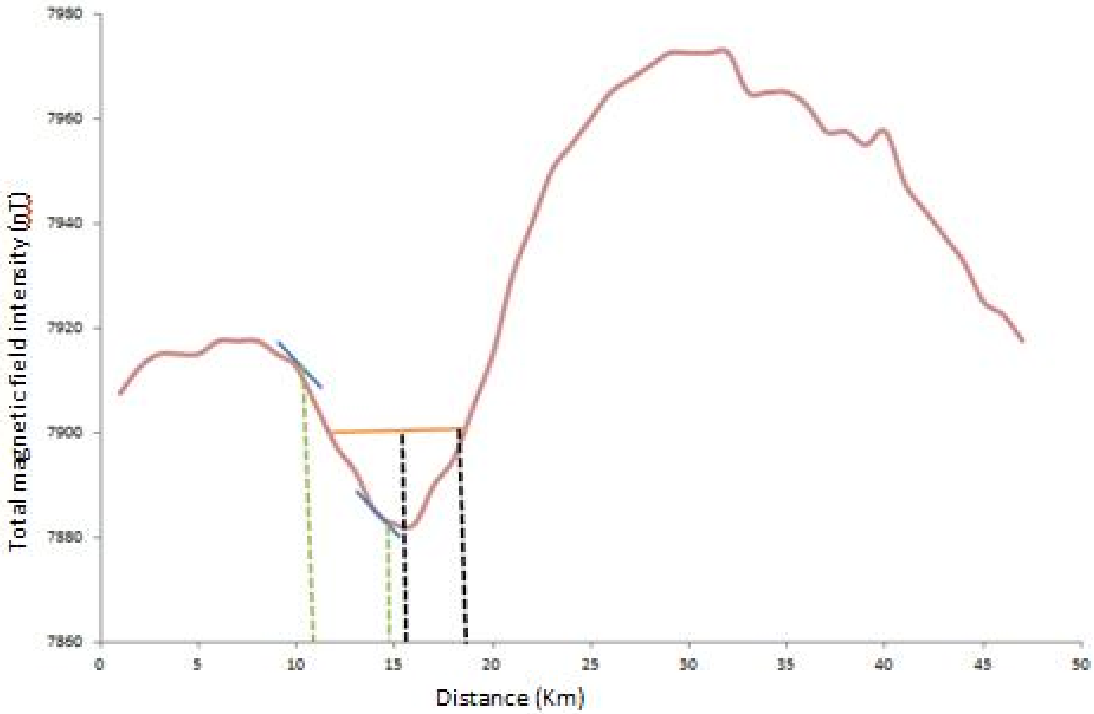

Fig. 11. Total Magnetic Field Profile along Afikpo showing locations of manual depth computed areas

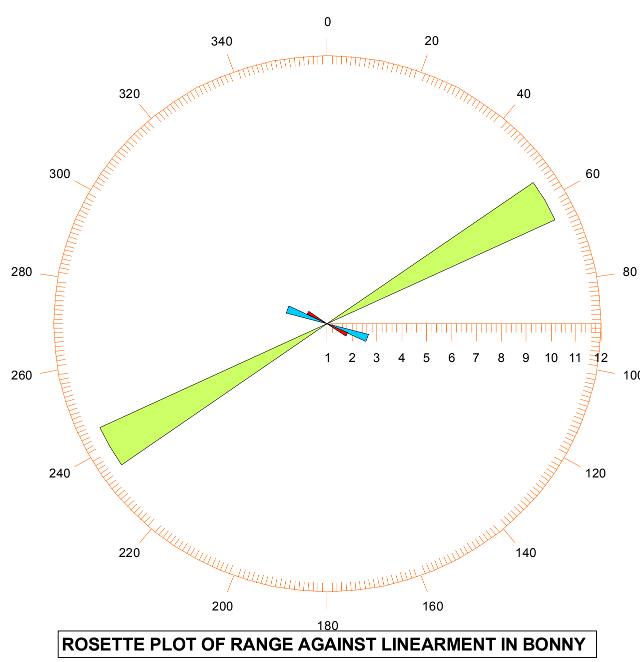

Fig. 12. Rosette diagram of lineament trends of Bonny – Niger Delta

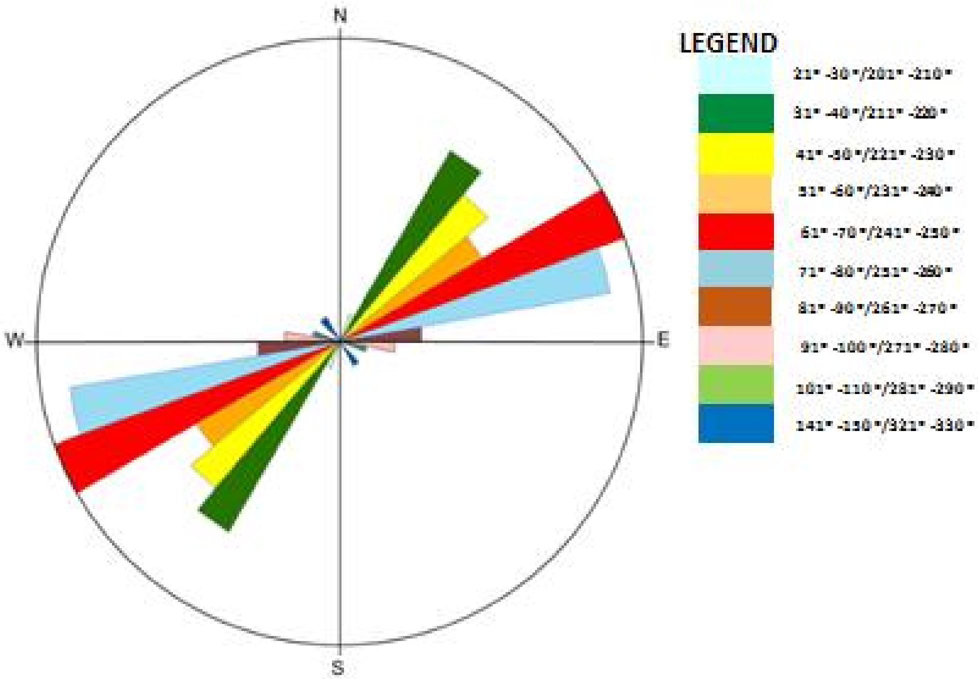

Fig. 13. Rose diagram for frequency distribution of lineaments in Ogoja(Lower Benue Trough)

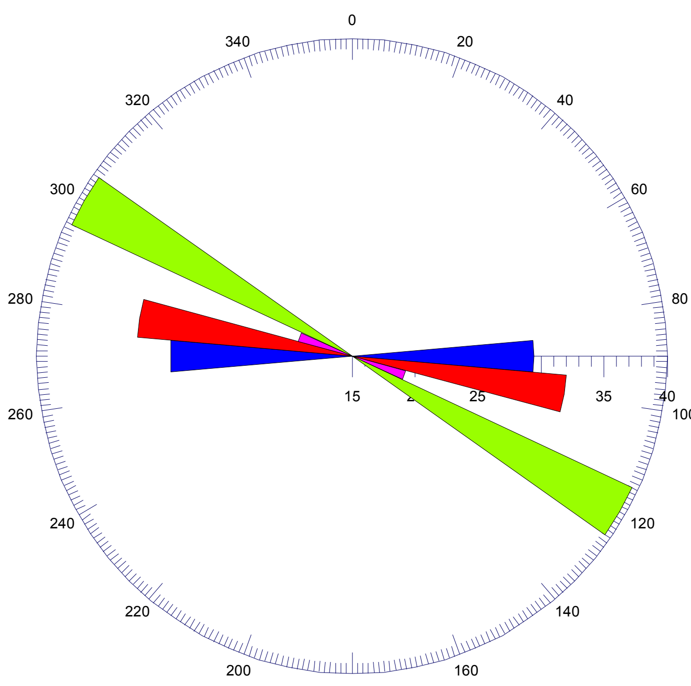

Fig. 14. Rosette diagram of lineament trends of Calabar/Oban – Calabar Flank Basin

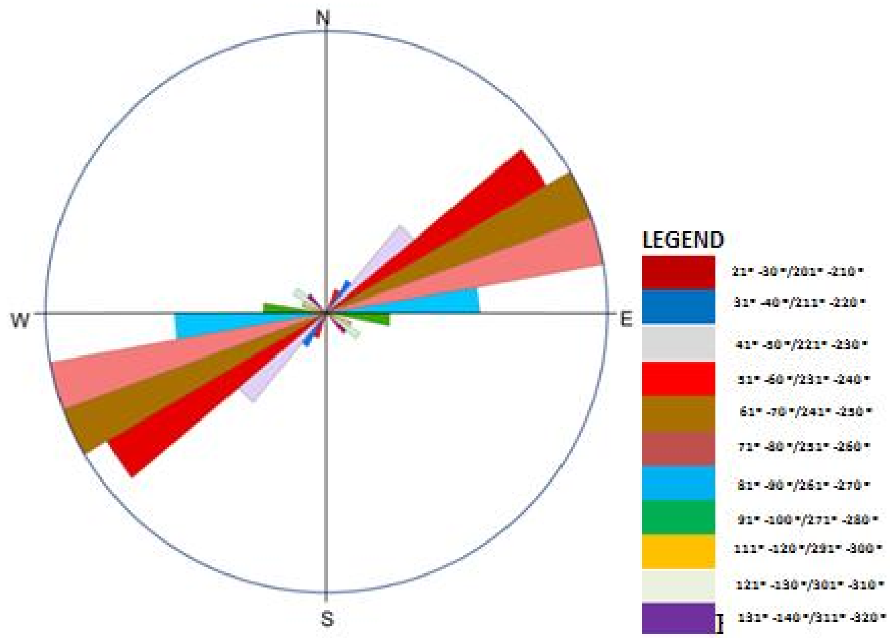

Fig. 15. Rosette diagram of lineament trends of Ikom – Mamfe basin

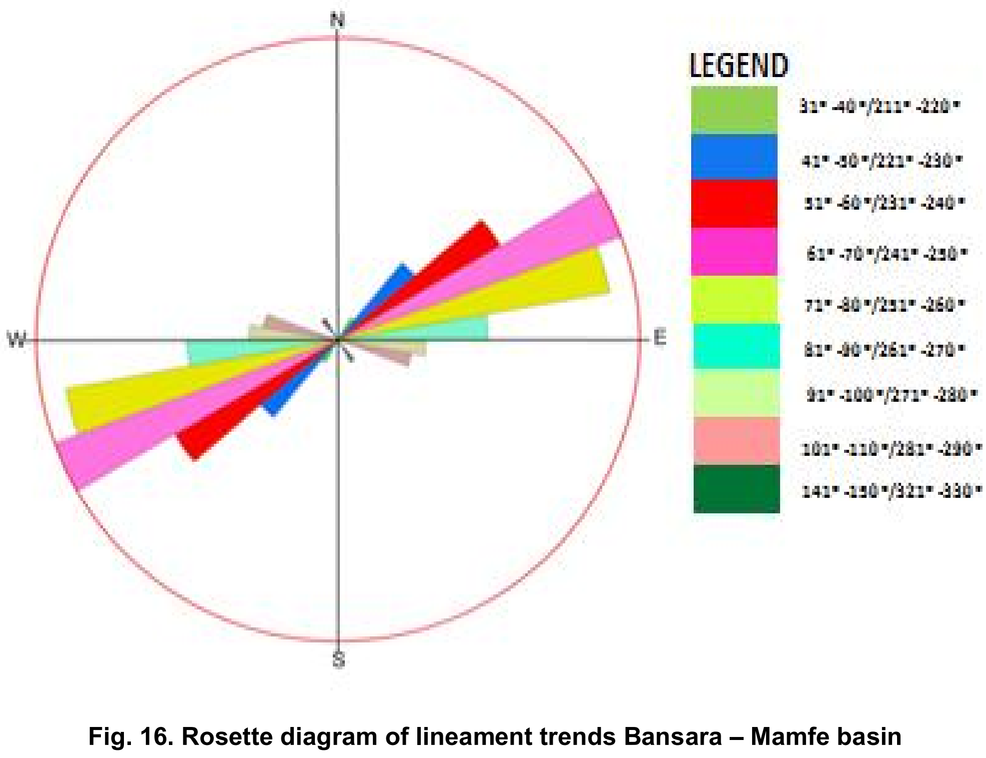

Fig. 16. Rosette diagram of lineament trends Bansara – Mamfe basin

Manually computed depth to source of magnetic anomalies indicate that widely spaced contours areas (deep seated) has greater depth of sediment accumulations which range between

3.5 km – 10.0 km, this occurred mostly around the Niger Delta towns (Aba 3.5 km, Obianga 4.5 km -5.0 km, Opobo 7.0 km , Port- Harcourt 8.8 km, Bonny 8.0 – 10.0 km , Bansara 3.4 km , and Ogoja 3.2 km). Also, the tightly spaced contour areas (Shallow seated) were found around the Calabar Flank, Anambra Basin, and Lower Benue Trough towns (Calabar 1.7 km – 2.5 km, Ikang 2.0 km – 3.0 km , Oban 0.5 km – 1.0 km , Ugep 1.9 km , Ikom 2.0 km , Nkalagu 2.1 km , and Abakaliki 2.2 km (Table 1.0). Lineaments trend analysis reveals that the major fracture patterns in the study area are in the NE – SW orientation covering the towns within the Niger Delta, Mamfe basin, Anambra basin, and Lower Benue Trough with only the Calabar Flank area showing a NW – SE orientations. This study reveals the presence of numerous fracture systems that could have controlled sedimentation patterns within these inland basins.

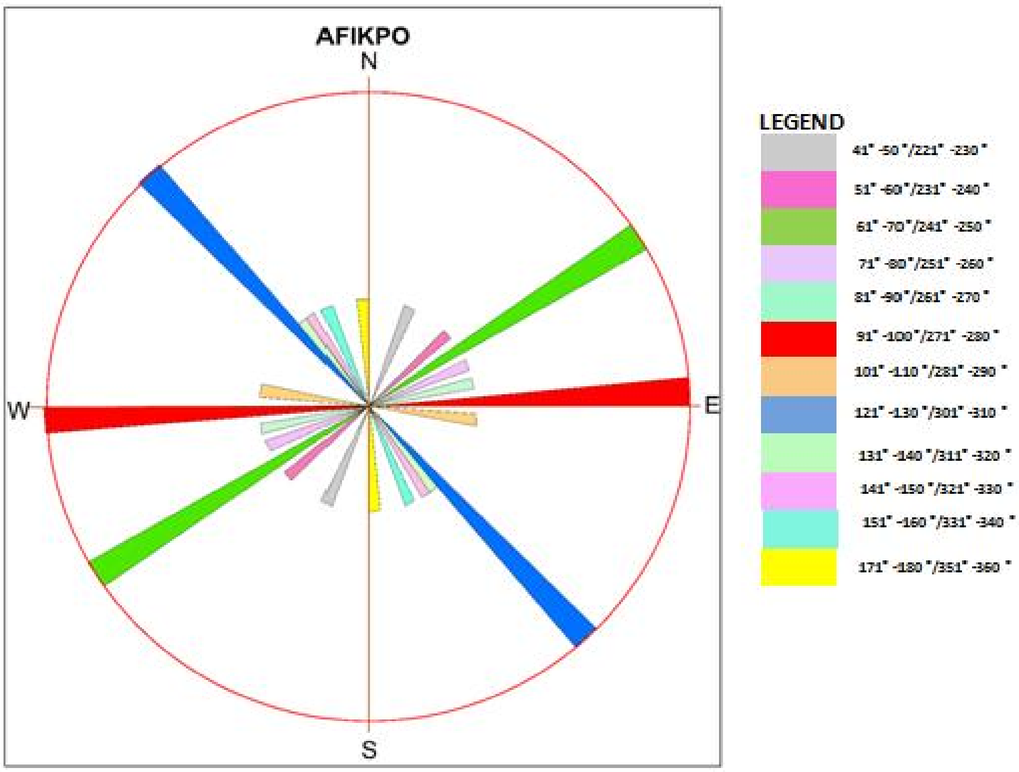

Fig. 17. Rosette diagram of lineament trends Afikpo – lower benue trough

Table 1. Manually computed depths from petters half width and mximum slope methods along profile lines

S/N	Town	Sheet no	Depth (KM)	Basin location
1.	CALABAR	331	1.75,3.0	Calabar Flank
2.	UWET	323	2.30	Calabar Flank
3.	OPOBO	330	7.0	Niger Delta
4.	BONNY	336	8.0, 10.0	Niger Delta
5.	OGOJA	290	3.2	Lower Benue Trough
6.	AFIKPO	314	2.6	Lower Benue Trough
7.	IKOM	315	2.0	Mamfe Basin
8.	BANSARA	304	3.4	Mamfe Basin

Table 2. Frequency distribution of lineaments in Ikom

Orientation (°)	Frequency	Length, L (Km)	Normal length (L/LT)	% of Normal length (L/LT) x 100
1-10/181-190	-	-	-	-
11-20/191-200	-	-	-	-
21-30/201-210	1	2.5	0.0260	2.60
31-40/211-220	2	2.7	0.0281	2.81
41-50/221-230	6	9.3	0.0968	9.68
51-60/231-240	13	17.0	0.1769	17.69
61-70/241-250	14	18.5	0.1925	19.25
71-80/251-260	14	21.2	0.2206	22.06
81-90/261-270	8	13.7	0.1425	14.25
91-100/271-280	3	7.0	0.0728	7.28
101-110/281-290	-	-	-	-
111-120/291-300	1	0.9	0.0094	0.94
121-130/301-310	2	2.4	0.0250	2.50
131-140/311-320	1	0.9	0.0094	0.94
2141-150/321-330	-	-	-	-
151-160/331-340	-	-	-	-
161-170/341-350	-	-	-	-
171-180/351-360	-	-	-	-
Total	**65**	**96.1**		**100.00**

Table 3. Frequency Distribution of lineaments in Ogoja

Orientation (°)	Frequency	Length, L (Km)	Normal length (L/LT)	% of Normal length (L/LT) x 100
-10/181-190	-	-	-	-
11-20/191-200	-	-	-	-
21-30/201-210	1	1.7	0.0241	2.41
31-40/211-220	8	14.1	0.1997	19.97
41-50/221-230	7	8.4	0.1190	11.90
51-60/231-240	6	11.2	0.1586	15.86
61-70/241-250	11	11.6	0.1643	16.43
71-80/251-260	10	10.7	0.1516	15.16
81-90/261-270	3	6.4	0.0906	9.06
91-100/271-280	2	2.6	0.0368	3.68
101-110/281-290	1	1.7	0.0241	2.41
111-120/291-300	-	-	-	-
121-130/301-310	-	-	-	-
131-140/311-320	-	-	-	-
141-150/321-330	1	2.2	0.0312	3.12
151-160/331-340	-	-	-	-
161-170/341-350	-	-	-	-
171-180/351-360	-	-	-	-
Total	**50**	**70.6**		**100.00**

Table 4. Frequency distribution of lineaments in the afikpo area

Orientation(°)	Frequency	Length (km)	Normal length (L/LT)	% of Normal length (L/LT x 100)
1-10/181-190	-	-	-	-
11-20/191-200	-	-	-	-
21-30/201-210	1	1.3	0.0233	2.33
31-40/211-220	-	-	-	-
41-50/221-230	1	1.5	0.0269	2.69
51-60/231-240	3	9.5	0.1708	17.08
61-70/241-250	1	1.2	0.0215	2.15
71-80/251-260	1	2.5	0.0449	4.49
81-90/261-270	3	6.0	0.1079	10.79
91-100/271-280	1	2.5	0.0449	4.49
101-110/281-290	-	-	-	-
111-120/291-300	-	-	-	-
121-130/301-310	-	-	-	-
131-140/311-320	3	15.3	0.2751	27.51
141-150/321-330	2	6.8	0.1223	12.23
151-160/331-340	1	3.0	0.0539	5.39
161-170/341-350	-	-	-	-
171-180/351-360	1	6.0	0.1079	10.79
TOTAL	**18**	**55.6**	**0.9994**	**99.94**

Table 5. Frequency Distribution of lineaments in the Calabar/Oban area

Orientation	Frequency	Li (Total Length)	Normalized length	Li x 100% / L
1-10	0		N .0	0
11-12	1	7.6	$1.6x10^{-2}$	1.6
21-30	1	11.4	$2.3 x10^{2}$	2.3
31-40	1	64.0	$13.1x10^{-1}$	13.1
41-50	1	10.8	$2.2x10^{2}$	2.2
51-60	4	154.7	$31.7x10^{-1}$	31.7
61-70	1	50.0	$10.2x10^{-1}$	10.3
71-80	1	28.5	$5.8x10^{-2}$	5.8
81-90	1	22.0	$4.5x10^{-2}$	4.5
91-100	5	84.9	$17.2x10^{-1}$	17.2
101-110	1	26.0	$5.3x10^{-2}$	5.3
111-120	1	13.0	$2.66x10^{-2}$	2.7
121-130	0	0	0	0
131-140	1	10.0	$2.05x10^{-2}$	2.1
141-150	1	4.5	$9.23x10^{-3}$	0.9
151-160	0	0	0	0
161-171	0	0	0	0
171-180	0	0	0	0
		EG = L = 487.4		99.7%

Table 6. Frequency distribution of lineaments in bonny/Port Harcourt

S/n	Orientation of anormaly (°)	Mid point(°)	Frequency of anormaly	% of frequency	Length of anormaly (m)	Normalized length	% of normalized length
1	1-10/181-190	5					
2	11-20/191-200	15					
	21-30/201-210	25	1	5	23419.90	0.0316	3
4	31-40/211-220	35	2	11	60077.87	0.0812	8
5	41-50/221-230	45	1	5	131080.40	0.1771	18
6	51-60/231-240	55	4	21	211558.53	0.2858	29
7	61-70/241-250	65	3	16	96553.27	0.1304	13
8	71-80/251-260	75	1	5	14641.64	0.0198	2
9	81-90/261-270	85					
10	91-100/271-280	95					
11	101-110/281-290	105					
12	111-120/291-300	115	3	16	134818.35	0.1821	18
13	121-130/301-310	125	1	5	25266.05	0.0341	13
14	131-140/311-320	135					
15	141-150/321-330	145	1	5	4893.62	0.0066	1
16	151-160/331-340	155	1	5	20873.63	0.0282	3
17	161-170/341-350	165	1	5	17119.66	0.0231	2
18	171-180/351-360	175					
19	TOTAL		19	100	740302.92	1	100

Table 7. Frequency distribution of lineaments in Bansara

Orientation (°)	Frequency	Length, L (Km)	Normal length (L/LT)	% of Normal length (L/LT) x 100
1-10/181-190	-	-	-	-
11-20/191-200	-	-	-	-
21-30/201-210	-	-	-	-
31-40/211-220	2	3.2	0.0201	2.01
41-50/221-230	8	12.1	0.0760	7.60
51-60/231-240	14	17.8	0.1117	11.17
61-70/241-250	23	40.2	0.2523	25.23
71-80/251-260	21	36.3	0.2279	22.79
81-90/261-270	12	17.8	0.1117	11.17
91-100/271-280	7	16.3	0.1023	10.23
101-110/281-290	6	9.2	0.0578	5.78
111-120/291-300	1	1.5	0.0094	0.94
121-130/301-310	-	-	-	-
131-140/311-320	-	-	-	-
141-150/321-330	2	4.9	0.0308	3.08
151-160/331-340	-	-	-	-
161-170/341-350	-	-	-	-
171-180/351-360	-	-	-	-
Total	**96**	**159.3**		**100.00**

4. SUMMARY AND CONCLUSION

Twenty aeromagnetic maps were manually digitized and merged to produce a single total magnetic field intensity map which was subjected to several filtering methods such as regression analysis polynomial filtering, reduction - to – pole , and upwards continuation [17,19,18] . These methods combined with manual trends analysis were able to detect areas of anomalous trends indicated as deep and shallow seated structures. The Chain and Charcort fracture trends are well known subsurface fracture systems that gave rise to the formation of the Benue these study further revealed the existence of these structures and also reveals other deep seated and shallow seated fracture systems within the inland basins. The upwards continuation reveals that the ancient suture zone (Chain and Charcot) have similar characteristics to those revealed by the Bansara and Afikpo fracture systems. Depth of sediments thickness also support that these fracture systerms account for the formation of the inland basins.

Conclusively, this study has reveal other inland fracture trends such as the Bansara, Afikpo, and ogoja areas which could be sites of great sediment accumulation and can be excellent sites for further hydrocarbon exploration.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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