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AEROMAGNETIC MAPPING OF BASINAL STRUCTURES OVER PART OF NIGER DELTA, AND ITS IMPLICATION FOR HYDROCARBON MIGRATION AND ACCUMULATION

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ABSTRACT

Aeromagnetic imaging over part of Niger Delta was carried out with a view to interpret the anomalies over the area and to equally delineate the structural features suitable for hydrocarbon accumulation within the study area. Digitized composite aeromagnetic data covering the study area were used in this study. Data enhancement techniques such as second vertical derivative, first horizontal derivative and analytic signal were applied to enhance deep seated structures. Results of the Spectral Analysis revealed that the average thickness of the sediments vary from 4.8 to 10.5 km, large enough for hydrocarbon accumulation. The derivative maps revealed parallel to sub-parallel trending NE-SW fracture zones in the basement underlying the study area, coinciding with the landward extension of the deep oceanic Chain and Charcot fracture zones. Hence, the identified lineaments (faults or lithologic contacts) and structures in the area can be attributed to the tectonic setting of the area and probable migratory routes for hydrocarbon migration.

KEY WORDS: Aeromagnetic, Basement, Lineaments, Euler Deconvolution and Hydrocarbon accumulation.

INTRODUCTION

Hydrocarbon exploration has hitherto relied on the generally expensive seismic method with the magnetic method confined to traditional and conventional role of analyzing a prospective sedimentary basin in terms of the overall basin architecture (size and shape), depth to basement and basement configuration (Oladele *et al.,* 2009). Geophysical techniques with high cost-benefit ratio and from which results can be obtained rapidly are required to map intrasedimentary structures of interest in hydrocarbon exploration (e.g. Ako *et al.,* 2004, Ojo *et al.*, 2009) and when combined with well or seismic data, magnetic surveying will reduce exploration cost.

The aim of this study is to delineate the magnetic lineaments and basement structures that will favor hydrocarbon accumulation; to map out basement and intrasedimentary structures that have potential for hydrocarbon prospects. Finally, effort was made to establish a relationship between the magnetic lineaments and the basement topography and how this influences the hydrocarbon accumulation in the area.

The study area falls within the Niger delta Basin and bounded by longitudes 4 ^{0} 30' E and 7 ^{0} 30' E, and latitudes 4.0 ^{0} N and 5.0 ^{0} N. It is located in the southern part of Nigeria (Fig. 1). The basin is flanked on the northwest by a thick outcrop of uppermost Cretaceous sedimentary rocks, which in turn rest unconformably on an extensive Precambrian Basement Complex. A narrow step-faulted hinge zone trending northwest-southeast marks the transition from Niger Delta Tertiary growth fault tectonics to the uniformly dipping beds of the Upper Cretaceous delta (Stoneley, 1966; Nwachukwu and Odjegba, 2001). The Eastern and northeastern flank of the Upper Cretaceous delta is tectonically and sedimentologically more varied. The most prominent feature is the Abakaliki high, which includes a succession of Aptian-Santonian Siliciclastic rocks that were subjected to compressive deformation towards the end of the Santonian. As a result of this deformation, the centre of deltaic deposition was displaced westward to fill the Anambra Basin (Murat, 1972). Throughout the post-Santonian period to the Paleocene, the Anambra Basin was the centre of deposition for several pro-delta cycles until a major northward marine transgression took place. The Imo Shale was deposited during this transgression. At the end of this transgression, the progradation that formed the present day Niger delta, was initiated.

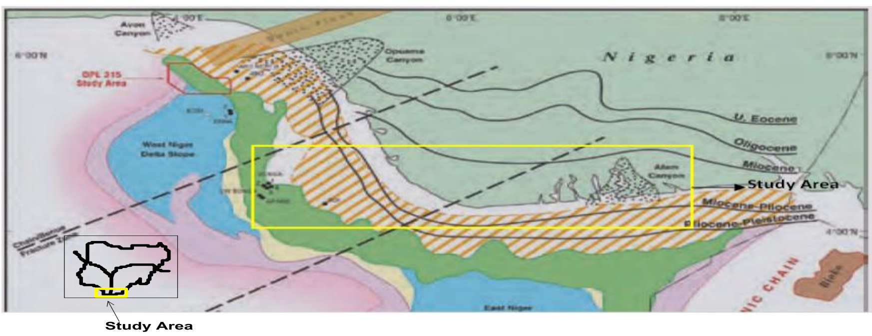

Fig. 1: Outline geologic map of Niger Delta showing the location of the study area(Modified from Techlink, PGS Geophysical, 2006)

MATERIALS AND METHODS

Processed aeromagnetic data by Nigeria Geological Survey Agency, covering the study area, was utilized in this study. Total Magnetic Intensity (TMI) map, Reduction to Equator (RTE) map and Residual TMI were produced using the Oasis montaj geophysical software. The RTE map was produced using a geomagnetic inclination of -18.5 and a declination of - 6.5 in order to correct for offset between the locations of anomalies and their sources which is a consequence of inclination of earth's field at a given location (Grauch *et al.*, 2004). The residual field was produced by removing high wavelength anomaly (regional) from the RTE data. Magnetic lineaments within the sedimentary basin were thus delineated from Vertical and Horizontal derivative maps. Euler Deconvolution and Tilt angle techniques were carried out on the upward continuation to 10 km of the residual data (Fig. 4b) with a view to map the basement structures. Furthermore, Structural Index of 0, maximum % tolerance of 15 and window size of 10 were employed in the Euler Deconvolution. The average thickness of the sedimentary basin was determined using spectral analysis (Spector and Grant, 1970). The GM-SYS^{TM} module of Oasis montaj software was employed in modeling the digitized data to determine the variation in thickness of the sedimentary basin. Fig. 2 showed the removed regional field by upward continuation of the RTE grid to 50km.

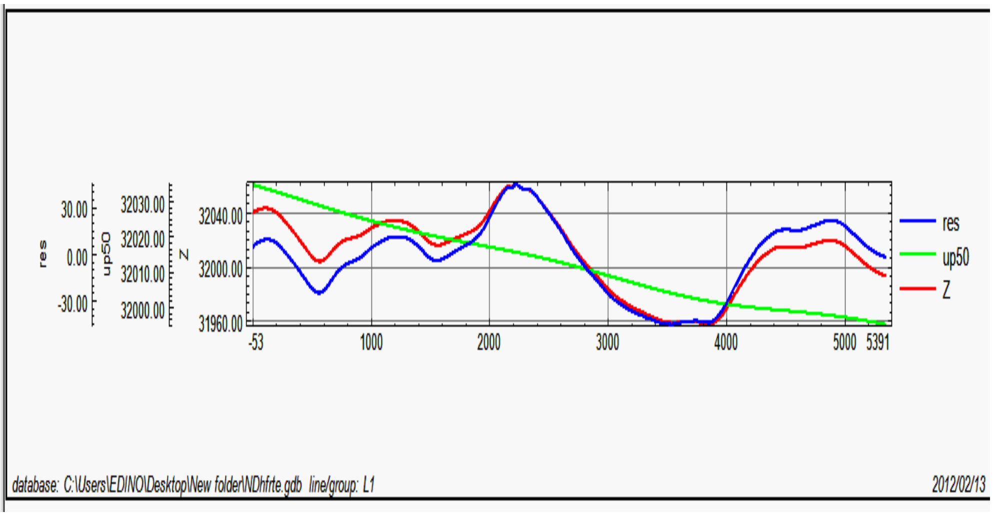

Fig. 2: Graph showing the RTE (red), regional (green) and residual (blue) for upward continuation to 50km

RESULTS AND DISCUSSION

The TMI, RTE and residual maps (Fig. 3a, 3b and 4a) of the study area are relatively subdued in a manner typical of sedimentary terrain. The anomalies of the reduced data (Figure 3b) show a northward shift relative to the anomalies of the raw data (Figure 3a). The dominant long wavelength anomalies on the maps (Fig. 3a, 3b and 4b) are certainly due to deep seated basement under the basin. The magnetic highs and lows are paired together, with the highs usually on the northern side of lows. Visual inspection of the maps revealed that the most dominant trend is in the NE-SW direction, which is related to the Pan African trend and corresponding to the trend Niger Delta. Trend in the E-W direction was also observed in the central area of the map.

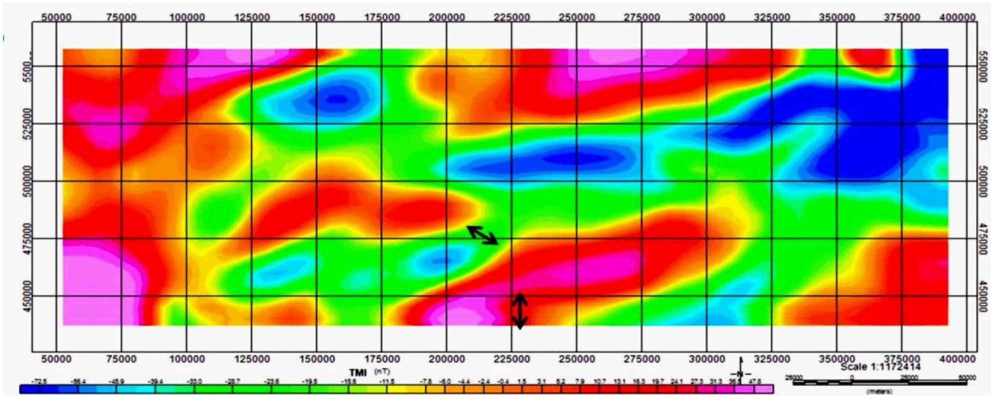

Fig. 3a: Total Magnetic Intensity Map (TMI) of the Study Area

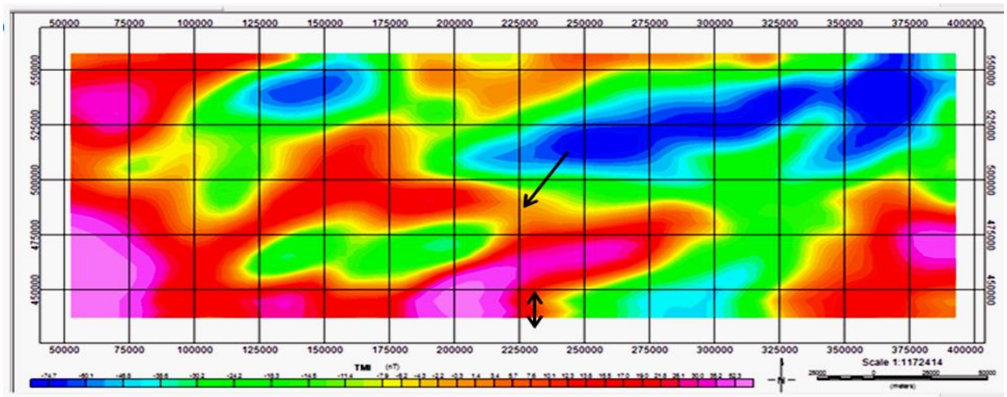

Fig. 3b: Reduction to Equator map of the study area (Arrows indicating a northward shift)

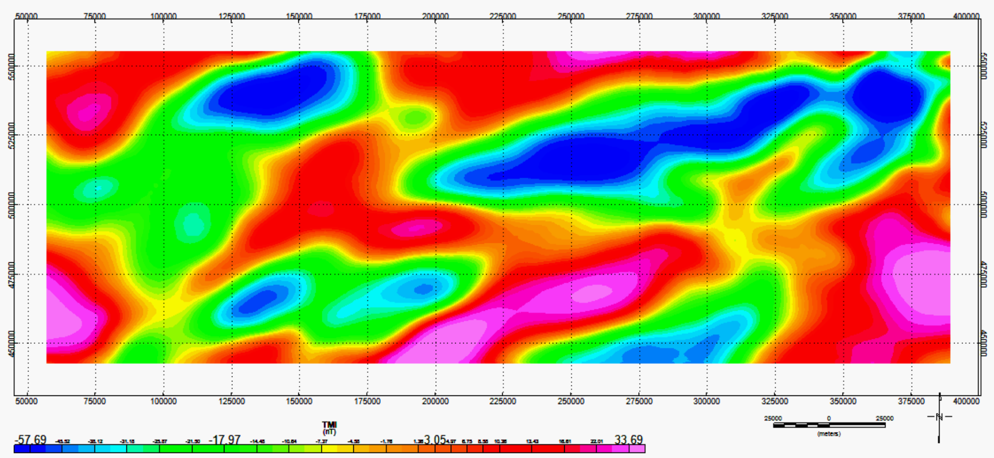

Fig. 4a: Residual Map of the study area

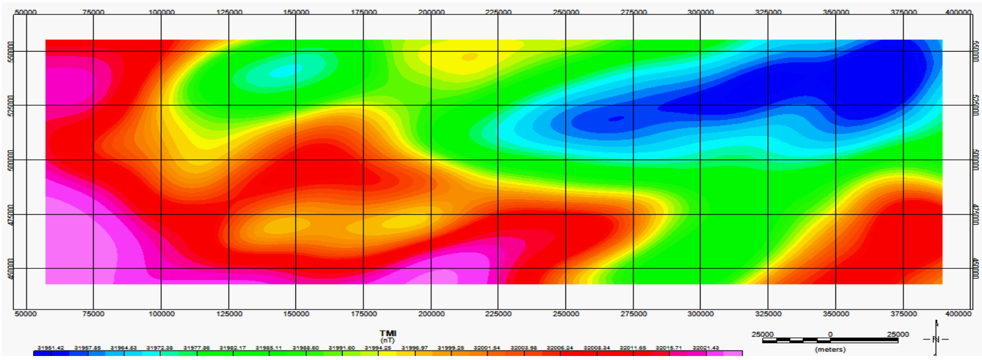

Fig. 4b: Upward continuation to 10 km of the Residual map of the study area

Depth to magnetic sources thickness of sediments: The number of magnetic horizons in the study area with their corresponding average depths was computed using the power spectrum method and two layers were obtained (Fig. 5a). The study area was divided into 21 blocks (Fig. 5b) and the spectral analysis was applied to each block. Results of this analysis showed that, the maximum depth to basement was 10.5 km at block 4 in the southern part of the study area. This is in agreement with the results of Akaegbobi *et al.*, (2000), and Whiteman, (1982), Ako *et al.*, (2004), who suggest that the sedimentary thickness increases towards the southern part of basin, attaining a maximum value of 12 km with an approximate value of 9 km siliciclastic sedimentary strata respectively. The shallow part was 4.8 km deep, at block 17, in the northeastern part of the area. The deeper part of the study area, located in the south, is presumed to have the thickest source rock deposits i.e. the area with the greatest potential for accommodation space or accumulation sites for hydrocarbon.

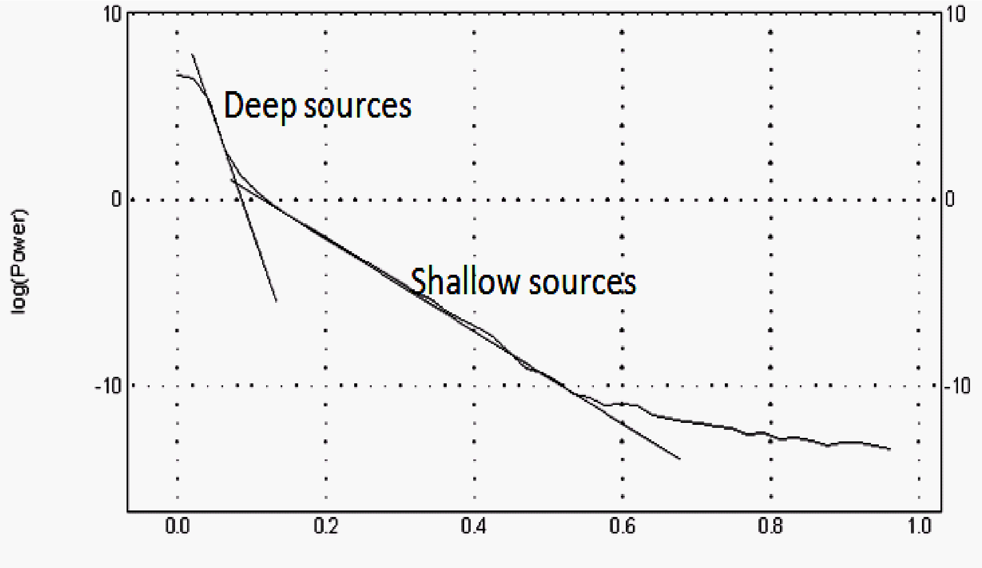

Fig. 5a: Radially averaged power spectrum (showing the two magnetic horizons for block 2)

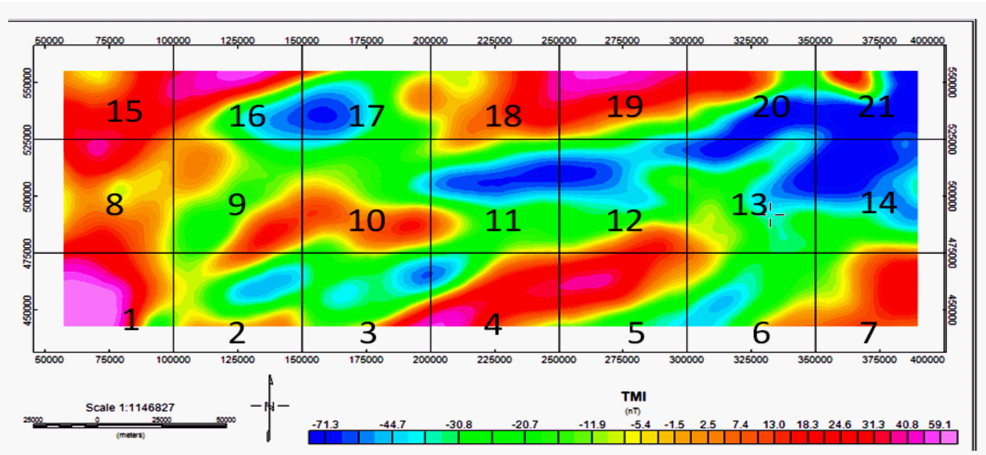

Fig. 5a: TMI map showing the division of the study area into 21 blocks

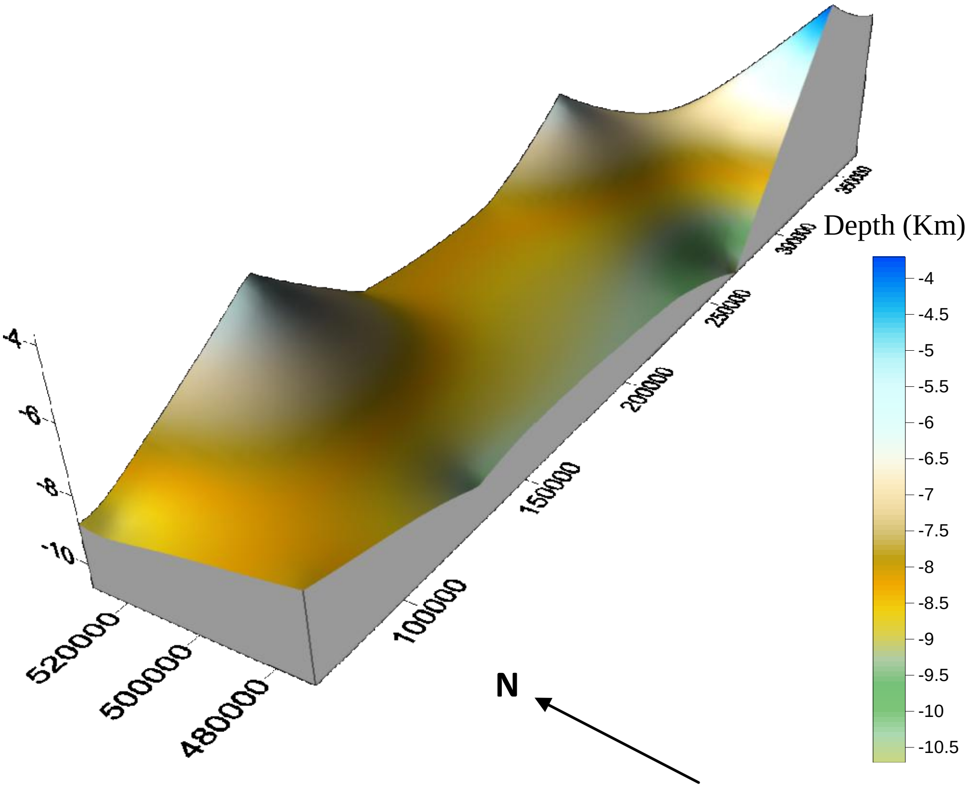

Fig. 5c: 3-D basement topography of the study area

Magnetic Lineaments Produced by Applied Techniques: Fig. 6a, 6b, 6c, 6d, show the horizontal derivative (HD) and second vertical derivative (2VD) maps, tilt angle and Euler solutions respectively. Comparing the locations of the mapped lineaments (interpreted to be faults) on these maps revealed a consistent parallel to sub-parallel trending NE-SW (faults, F1-F9) and NW-SE (fault, F10) fracture zones. These trends correlated with the results of Ofoegbu and Mohan (1990), and Ako, *et al*. (2004). F10 truncates F8 and F9, The lineament F1 correspond to the Chain fracture zone while F3, F4, F5, F6, F7, F8 and F9 are associated with the Charcot fracture zone (Doust and Omatsola, 1990, Lauferts H., 1998 and Benkhelil *et al*., 1998). They were believed to be formed during the opening of the mid-Atlantic Ocean in the late Jurassic to early Cretaceous times (Haack *et al*, 2000). This correlation was clearly captured by Fig. 7.

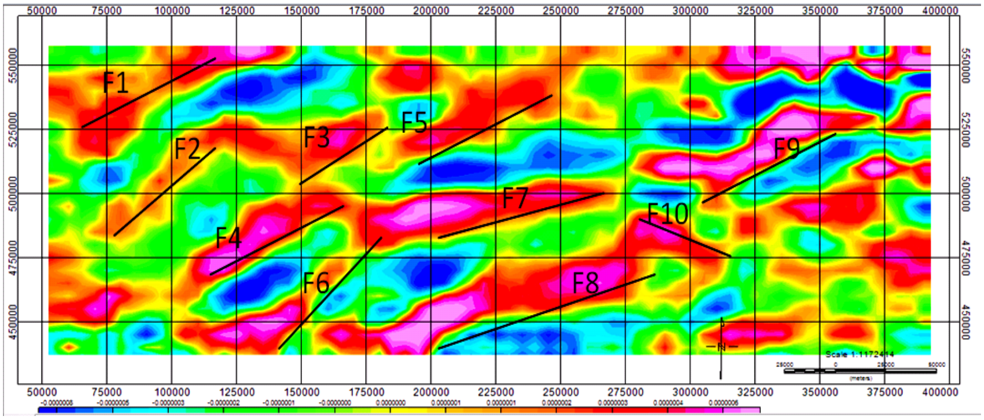

Fig. 6a: Horizontal derivative map of the study area

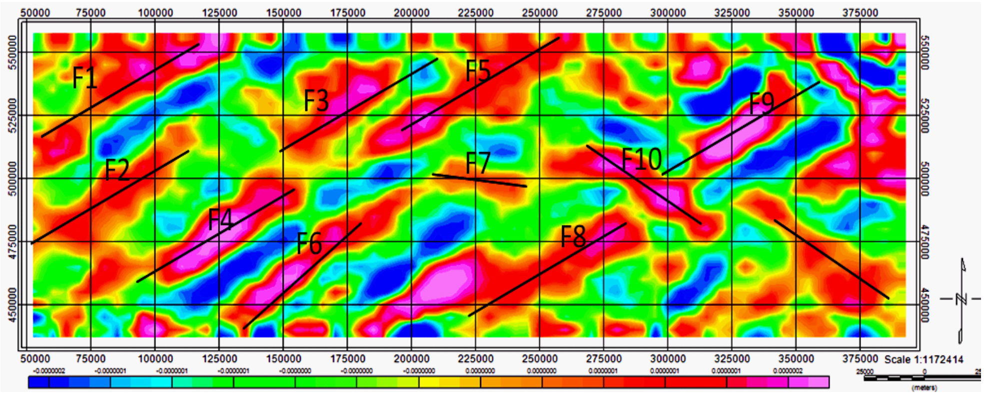

Fig. 6b: Vertical derivative map of the study area

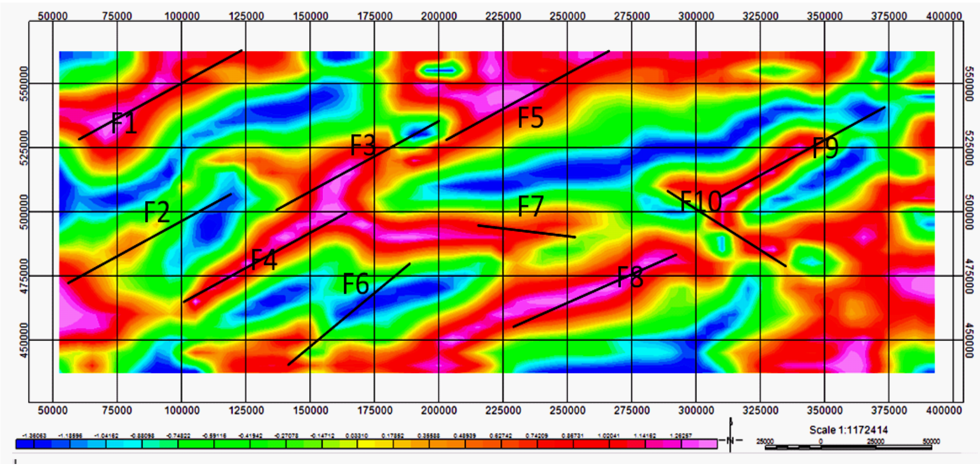

Fig. 6c: Tilt angle map of the study area

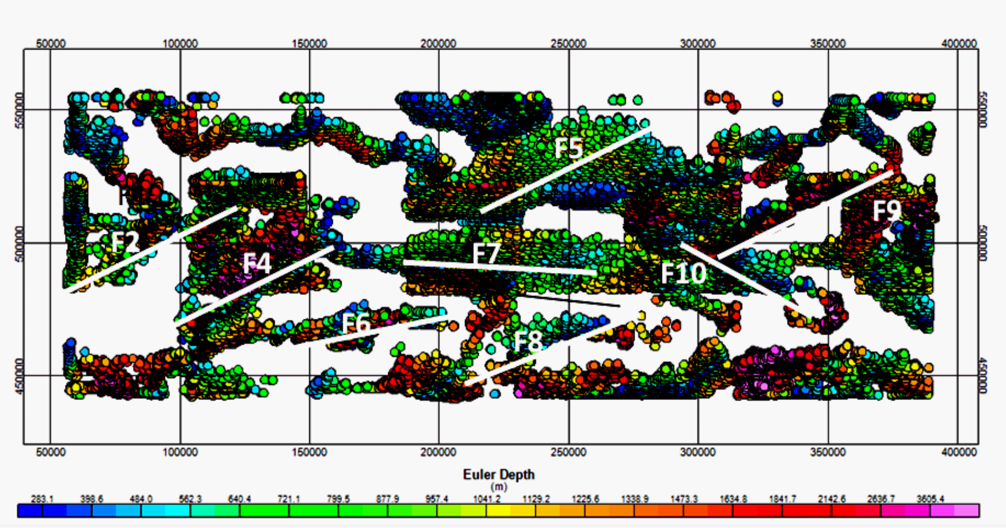

Fig. 6d: Euler Deconvolution (for all solutions) Map of the study area

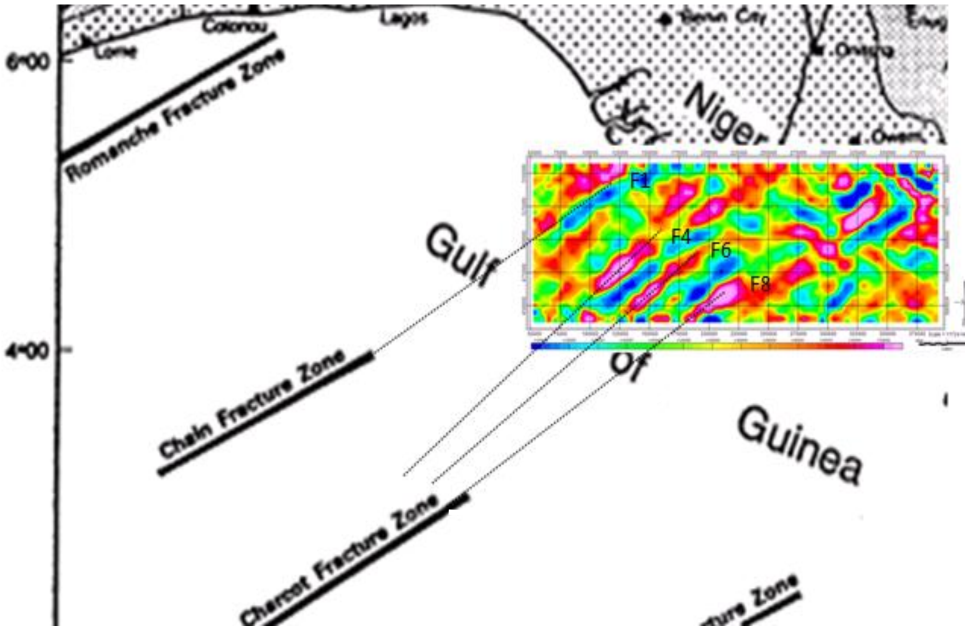

Fig. 7: Correlation of mapped fractured zones FZ1 – FZ4 with tectonic map of the Niger Delta (Modified after Benkhelil et al., 1998).

Magnetic Depth Slicing: Integrated basin analysis begins from the basement, and then proceeds to the sedimentary section. To correlate the structural features of the basement with those of the sedimentary section, Euler solutions were windowed to produce only solutions that originate from the sedimentary column. Fig. 8a, 8b and 8c showed Euler Deconvolution depth slices at 0-3 km, 3-6 km and 6-9 km respectively. The depth slices yielded only lineaments permeating the sedimentary section. Visual inspection of the maps indicates that the solutions are aligned in a NE-SW trend. These solutions correlated with basement lineaments obtained from horizontal derivative map, second vertical derivative map and tilt angle method (Fig. 6a, Fig. 6b, and Fig. 6c). This suggests that the sedimentary section was influenced by the underlying basement architecture. Hence, the alignment of Euler depth solutions (Fig. 6d) at all depths suggests also that the basement lineaments permeate the sedimentary section within the study area.

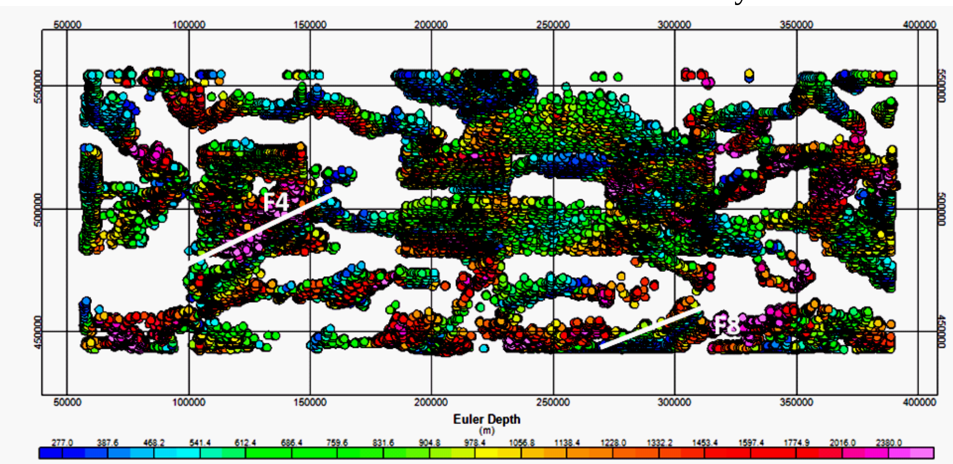

Fig. 8a Euler depth slice for solutions between 0-3 km

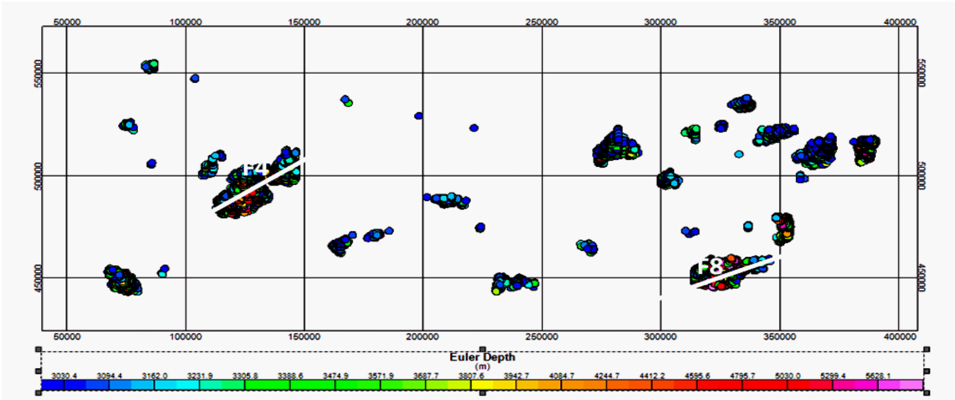

Fig. 8b: Euler depth slice for solutions between 3-4 km

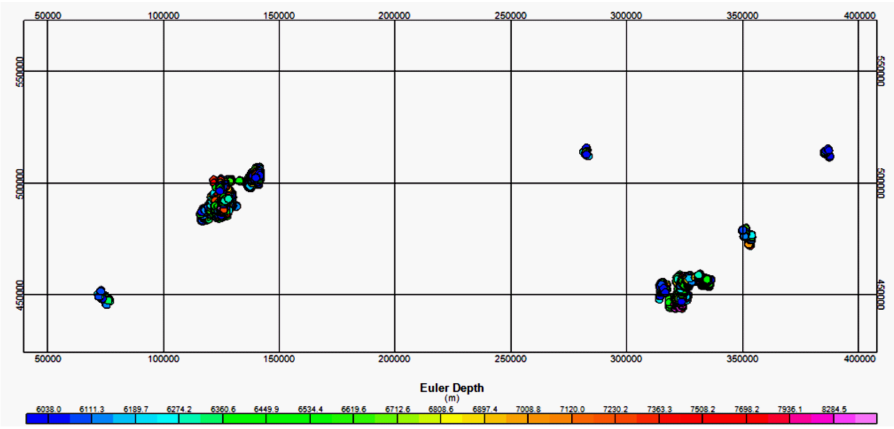

Fig. 8c: Euler depth slice for solutions between 6-9 km

Correlation between Lineament and Basement Topography: The locations of the mapped magnetic lineaments (Fig. 6a, 6b, 6c and 6d) coincide with the inflexion between basement highs and lows (Fig. 5c). This observation can be explained by the faultings that result in horst and garben. Horsts are the basement highs while the garbens are the basement lows. The likely trapping mechanism in the sedimentary section above these areas is the drape-compaction anticline, (Peirce *et al*., 1998), formed as a result of beds being draped over an upfaulted blocks of the basement rock. These suggest that the fracture zones might be migration paths for hydrocarbon.

Structural Pattern and Hydrocarbon Exploration: Knowledge of the structural pattern in the basement can be used in hydrocarbon exploration to lay out new/ infill 3D seismic programs and to ease the interpretation of existing 3D seismic programs. The second vertical derivative map (Fig. 9) showed how magnetic lineaments can be used for selecting locations for seismic lines within the study area on the assumption that all the basement faults propagate through the sedimentary section. Lines A, B, and C follow a very closely parallel faults and would be poor locations to run seismic lines due to the probable poor seismic definition attributable to fracturing and faulting along these zones. Lines E, F, G and H, on the other hand, will be good locations to run seismic lines in order to properly define the faults and lithologic contacts on seismic sections. The Line G may not be able to define the fault, F 10. Therefore line C will be recommended for the fault, F 10.

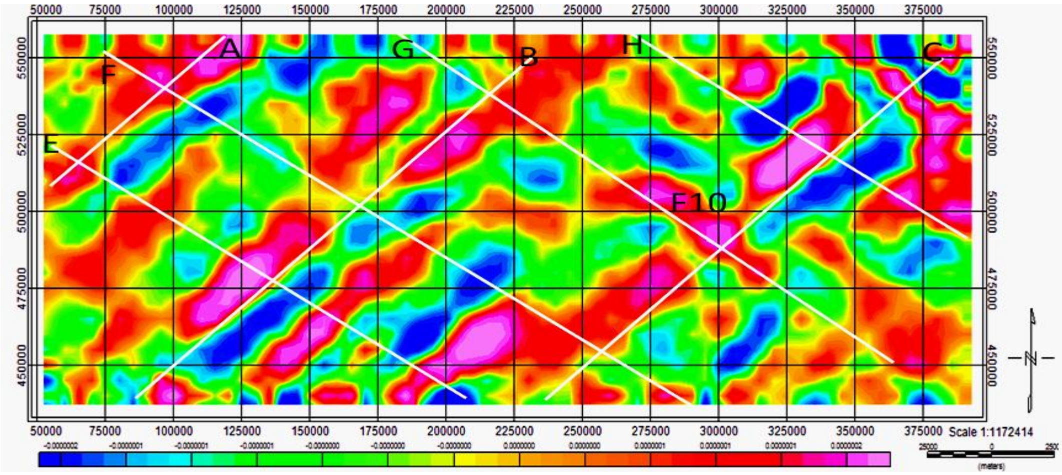

Fig.9: Second Vertical Derivative Map

CONCLUSION

Results of horizontal derivative (Fig. 6a), vertical derivative (Fig. 6b), tilt angle method (Fig. 6c) and Euler Deconvolution (Fig. 6d) showed a very remarkable correlation in trend and location of the mapped lineaments in the study area. More also, magnetic depth slicing (Fig. 8a, 8b, 8c) further revealed that a substantial part of the magnetic response in the study area is sourced from the basement, which strongly suggests that the sedimentary section has been influenced by the underlying basement structures. Result of the second vertical derivative (Fig. 9) will enhance rapid tectonic interpretation in a bid to understand the regional geology of the study area and will also facilitate planning of seismic lines/profiles within the prospective areas for hydrocarbon exploration. Hence, the association of the lineaments with faulted basement

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suggests a structural influence that will favor hydrocarbon accumulation and migration in the study area.

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