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Structural Evaluation of *SUZ* Field, Onshore Niger Delta, for Hydrocarbon Prospectivity using 3D Seismic Data.

[1]Anakor, S.N., [2]Obiadi, I.I., [3]Nwozor, K.K., [4]Okeke, S.E., and [5]Didi, C.N.
[1&3] Department of Geology, ChukwuemekaOdumegwuOjukwu University, UliCampus,Nigeria.
[2] Department of Geological Sciences, NnamdiAzikiwe University, Awka, Nigeria.

Abstract
Structural evaluation of SUZ field, onshore Niger Delta, for hydrocarbon prospectivity was studied using regional 3D seismic data. The objective of the study is to structurally evaluate the field with a view to identifying structural features such as faults, map geologic horizons and analyze reflection characteristics that might be a good lead to probable hydrocarbon accumulations. Results revealed that eleven faults (F1, F2, F3, F4, F5, F6, F7, F10, F11, F12, and F14) and five seismic horizons (S2, S3, S4, S7 and S9) were delineated on the seismic section. Fault 2 and 3 and 7 were extensive and represent a back to back fault. They are also regional growth fault. Fault 4, 5, 6, 10, 11, 12, and 14 are synthetic faults that dips basin ward (SE), while fault 1 is an antithetic fault that dips landward (NW). All interpreted faults had the hanging walls moved down relative to the foot wall. The five seismic horizons were delineated at 2290, 2200, 2120, 2100 and 2000 ms, respectively and are characterized by distinctive high amplitude reflection events. These horizons are indicators of top reservoir sands which correspond to peak amplitude (blue), and could be associated with both oil and gas with/without water contact. Two prospects in horizon S2 and S9 were identified and the potential for hydrocarbons is high in this prospect field based on this study, which could be explored.

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I. Introduction

Niger Delta Basin are among the most challenging successions in stratigraphic and structural interpretation in petroleum exploration because of the several factors involved in their tectono- stratigrapghic evolution. As a result, the search for oil and gas has become increasingly challenging facing these complexities and other problems associated with hydrocarbon accumulations. These challenges of the delta can be evaluated by the structural interpretation of 3D seismic data. The Niger Delta sedimentary basin comprises three fundamental lithostratigraphic units, each with defining stratigraphic and structural characteristics. These can be classified as topset beds, foresets and bottomset as revealed from seismic stratigraphy perspective (Galloway, 1975). The topset unit is a grossly regressive continental unit called the Benin Formation; the foreset unit is represented by the prograding Agbada Formation, whereas the marine clay/shale of the Akata Formation is the bottom set unit of the delta depositional system. The following main features constitute the structural framework of the Niger Delta basin: antithetic tilted step-fault blocks, synthetic untilted step-fault blocks, structural inversion axes, hinges with compensation grabens, homoclinal structures, growth faults with rollovers, shale diapirs, and structural features related to igneous activity. The hypothesized contemporaneous development of the two faulted block systems mentioned above constitutes a new viewpoint regarding to the evolution of the structural framework of the Niger Delta basin. Structural interpretation of 3D seismic data entails identifying, picking and tracking of laterally consistent seismic reflectors for the objective of mapping geologic structures, depth of primary reflector, stratigraphy and perhaps to probe reservoir architecture (Anstey, 1980; Mcquillin*et al.*, 1984; Allstair, 2011; Avseth*et al.*, 2005). The end result would be to detect traps with probable hydrocarbon accumulation.Many authors have attempted structural and stratigraphic interpretation in the Niger Delta using seismic data (ogboke, 2006; oyedele*et al*., 2013; obiekezie, 2014; odoh*et al*., 2014). These authors reported that structural and stratigraphic information relating to hydrocarbon traps and accumulation can be derived from the detailed analysis of 3D seismic data and well logs.Structural and stratigraphic analysis of seismic data is key to reservoir evaluation and has become the main tool in the exploration of hydrocarbon reservoirs (Bahorich and Farmer, 1995; Sheriff and Geldart, 1995).

The objective in this study is to structurally interpret a 3D seismic data in the central swamp depobelt of the *SUZ*-Field in the Niger Delta Basin by delineating and classifying faults, estimate their orientations and dips, map horizons and analyze reflection characteristics that may be associated with hydrocarbon accumulation in the field.

II. Location Of The Study Area

The field under investigation lies in the central swamp depobelt of the Niger delta in Nigeria (Figure 1). The field belongs to an active oil producing company in Nigeria (Shell Petroleum Development Company). The field is located in Southern Nigeria, between latitudes 4°10^{1}58.49^{11}N and 4°16^{1}29.04^{11}N, and longitudes 6°59^{1}1.24^{11}E and 7°7^{1}50.34^{11}E. The five (5) wells; SUZ 1, 2, 3, 8 and 9 provided were aligned in the northwestern to the southeastern direction within the study area.

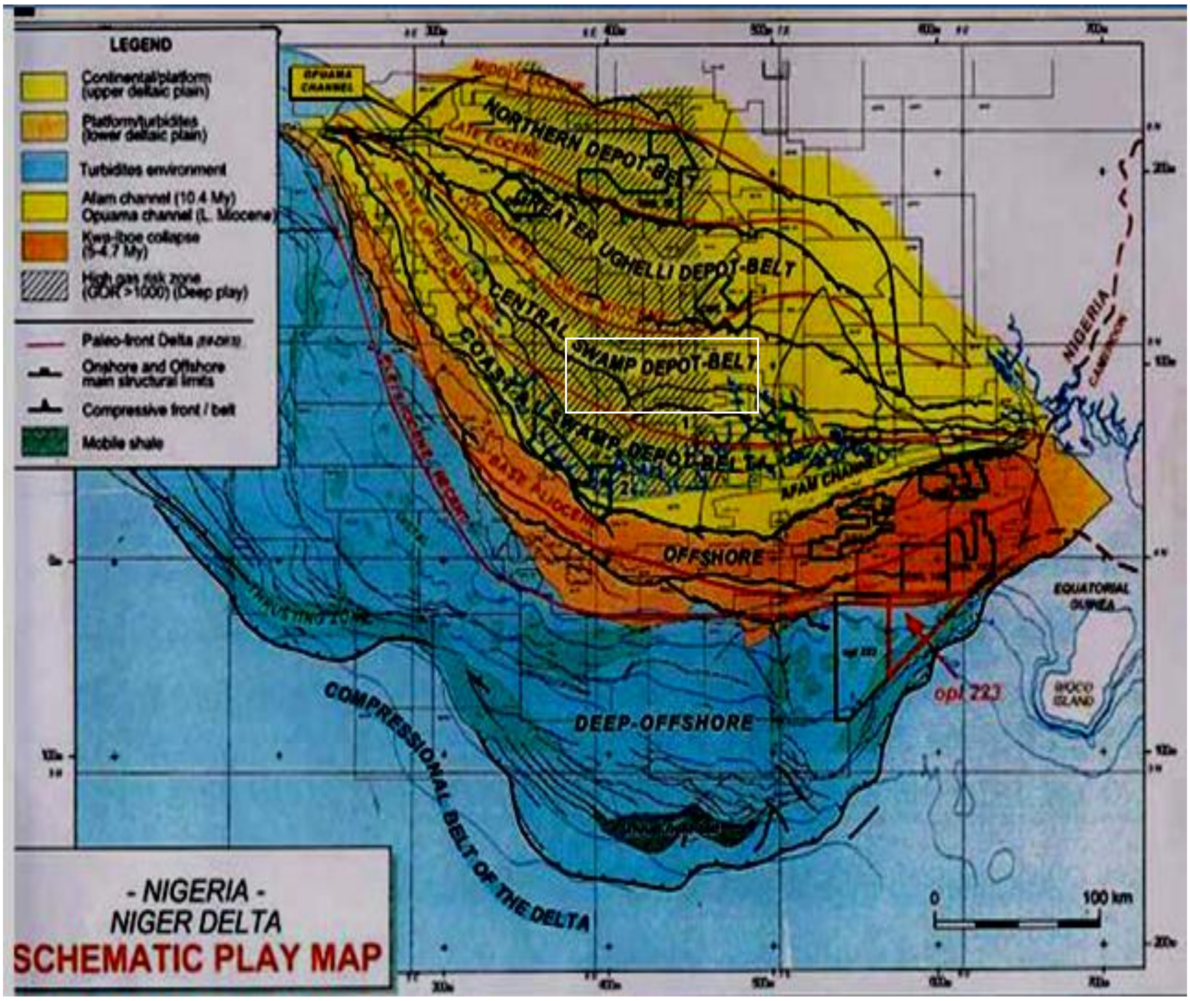


Figure 1: Location map of Niger Delta showing the study area. (Nwozor*et al.* 2013)

GEOLOGY OF THE STUDY AREA

The Niger Delta basin is underlain by three stratigraphic units, the top Benin Formation, the middle Agbada Formation and the deepest Akata Formation. The Benin Formation consists mainly of continental sand deposits with intercalation of shale and constitutes the main aquiferous unit of the basin. The formation is covered with topmost low velocity layer which, in most cases, is weathered within which surface waves are excited and generated. Immediately below the Benin Formation is the reservoir sand of the Agbada Formation which is believed to house the oil and gas resource of the Niger Delta. The Agbada Formation consists of unconsolidated to slightly consolidated paralic siliciclastic sequence of sandy unit with minor shale intercalations of about 4500 m thick (Weber and Daukoru, 1975). In the lower portion of the formation, shale and sandstone beds are deposited in equal proportion (50%), however, the upper section is mostly sand (75%) with minor shale intercalations. The Akata Formation at the base of the Delta is of marine origin and is composed of thick shale sequences (potential source rock), turbidite sand (potential reservoirs in deep water), and minor amounts of clay and silt. The formation underlies the entire delta, and is typically overpressured (Evamy*et al.*, 1978; Doust and Omatsola, 1989). The Tertiary Niger Delta is characterized by synsedimendary gravitational growth faults, developed as a result of rapid sand deposition and differential loading of coarser clastics over fine-grained under-compacted marine shales of the Akata Formation.Evamy et al. (1978) described the mode of formation, distribution and importance of growth faulting in the Niger Delta development. The growth faults are contemporaneous and more or less continuously active with deposition such that their throws increase with depth. The growth faults may be listric, typically cuspate normal faults, which flatten with depth into the thick clastic shally sequence of the Akata Formation. Continuous growth of the faults after their inception, allows for greater sedimentation on the down-thrown blocks relative to the upthrownblocks.Thissynsedimentary tectonic activity in the Niger Delta Basin gave rise to structural deformations, producing series of fault blocks. These fault blocks have been grouped together to form macrostructure, which are essentially large rollover deformation structures (Evamy*et al*., 1978). Each macrostructures is bounded up-dip by a structure building fault and varies greatly in areal extent and complexity. The complexity of macrostructures is indicated by the density and style of faulting and is more pronounced along the central axis of the delta. Each macrostructure is composed of one or more fault blocks with predominantly northwards dip, a zone of symmetrical anticlinal dips and a southerly dipping flank of variable extent (Evamy*et al*., 1978). The macrostructures are grouped into sets designated as megastructures.Weber (1971), Evamy*et al*., (1978) and Doust and Omatsola (1990) described a variety of structural trapping elements (Figure 2), including those associated with simple rollover structures, multiple growth faults, antithetic faults, and collapsed crest structures

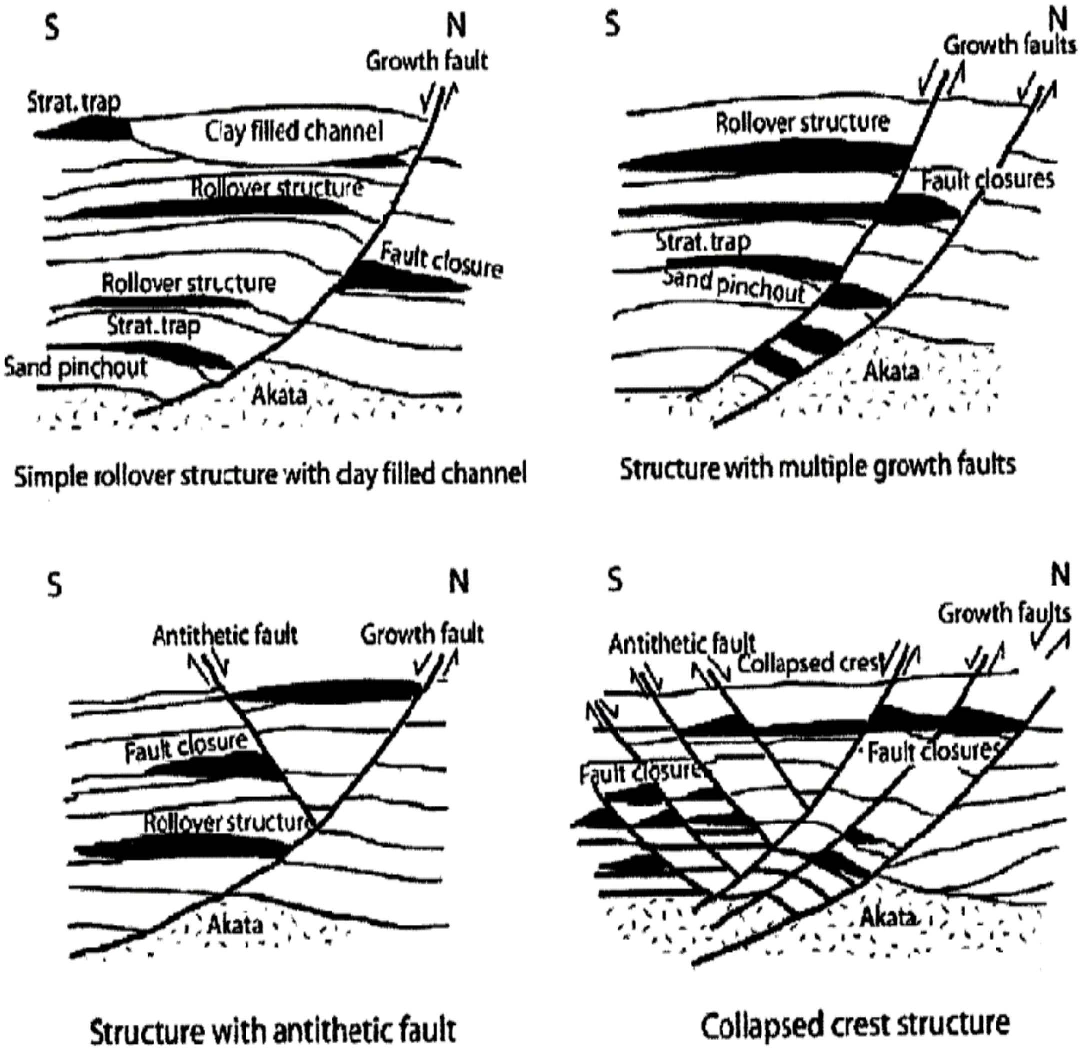


Figure 2: Major classes of structures (After Evamy*et al.,* 1978)

III. Methodology

The data set used for this analysis consist of 3D seismic volume and well data acquired from *SUZ*-Field in the central swamp depobelt of the Niger Delta Basin. The seismic volume (Figure 3) was imported into a user defined folder in SEG-Y format and loaded into Shlumberger petrel software 2015. The 3-D seismic data (figure 5) covers an area of 164.28sqkm^2. The bin spacing of the data is 25.00m (inline) by 25.00m (cross-line). The in-line (dip section) ranges from 4180-5275, while the cross-line (strike section) ranges from 759-1370 (Figure 4).

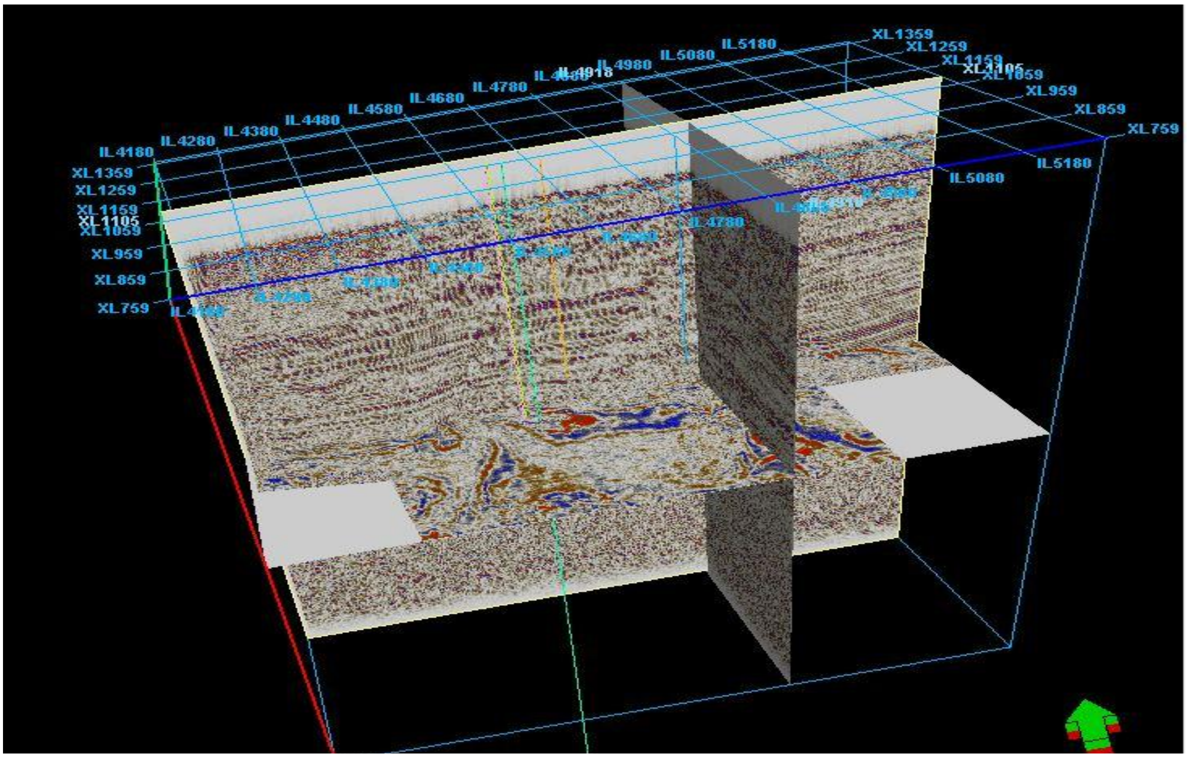
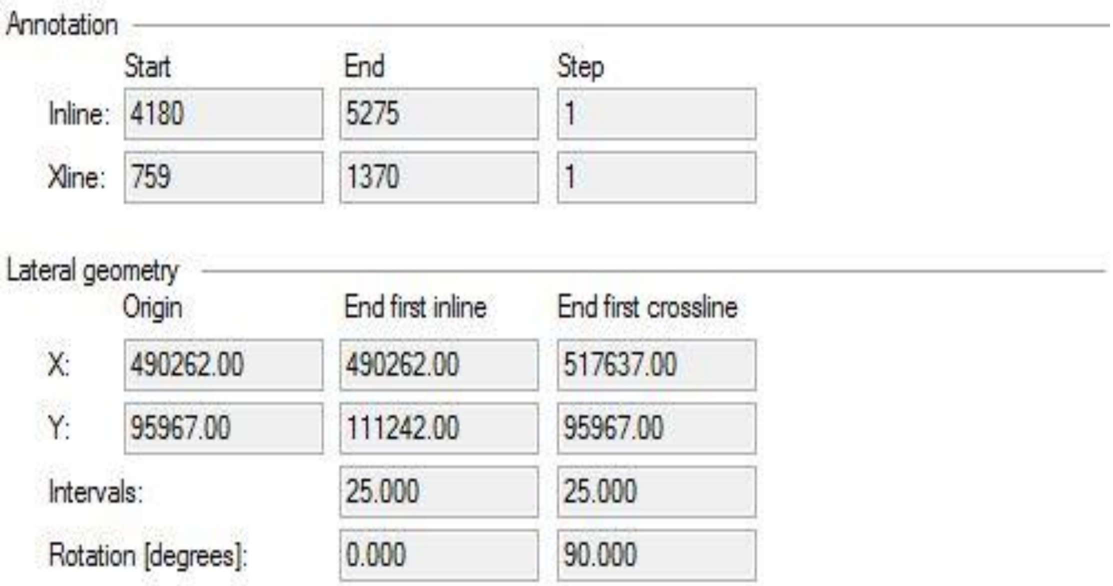


Figure 3: 3D visualization of the seismic volume



Annotation

	Start	End	Step
Inline:	4180	5275	1
Xline:	759	1370	1

Lateral geometry

	Origin	End first inline	End first crossline
X:	490262.00	490262.00	517637.00
Y:	95967.00	111242.00	95967.00
Intervals:		25.000	25.000
Rotation [degrees]:		0.000	90.000

Figure 4: Seismic data acquisition parameter

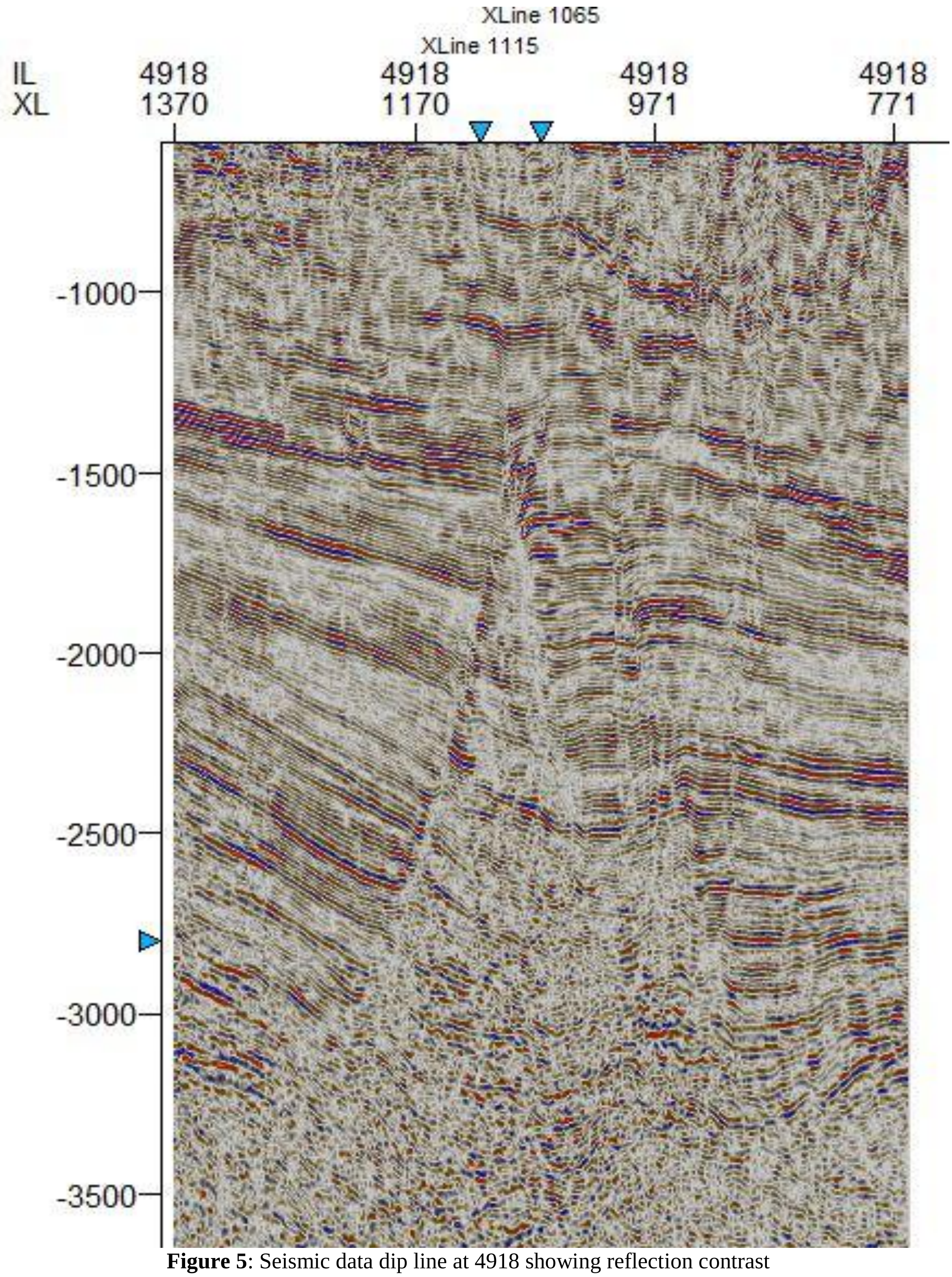


Figure 5: Seismic data dip line at 4918 showing reflection contrast

The identification of faults and mapping of seismic horizons were based on the work flows in Figure 6. This entails visually inspecting the seismic section for reflection discontinuities, vertical displacement of reflection events and abrupt termination of events, overlapping of reflections and changes in pattern and strength of reflection events across the seismic section. Based on this, faults are delineated, horizons indicating reservoir tops from information obtained from well logs are mapped across the section.

IV. WORKFLOW DIAGRAM

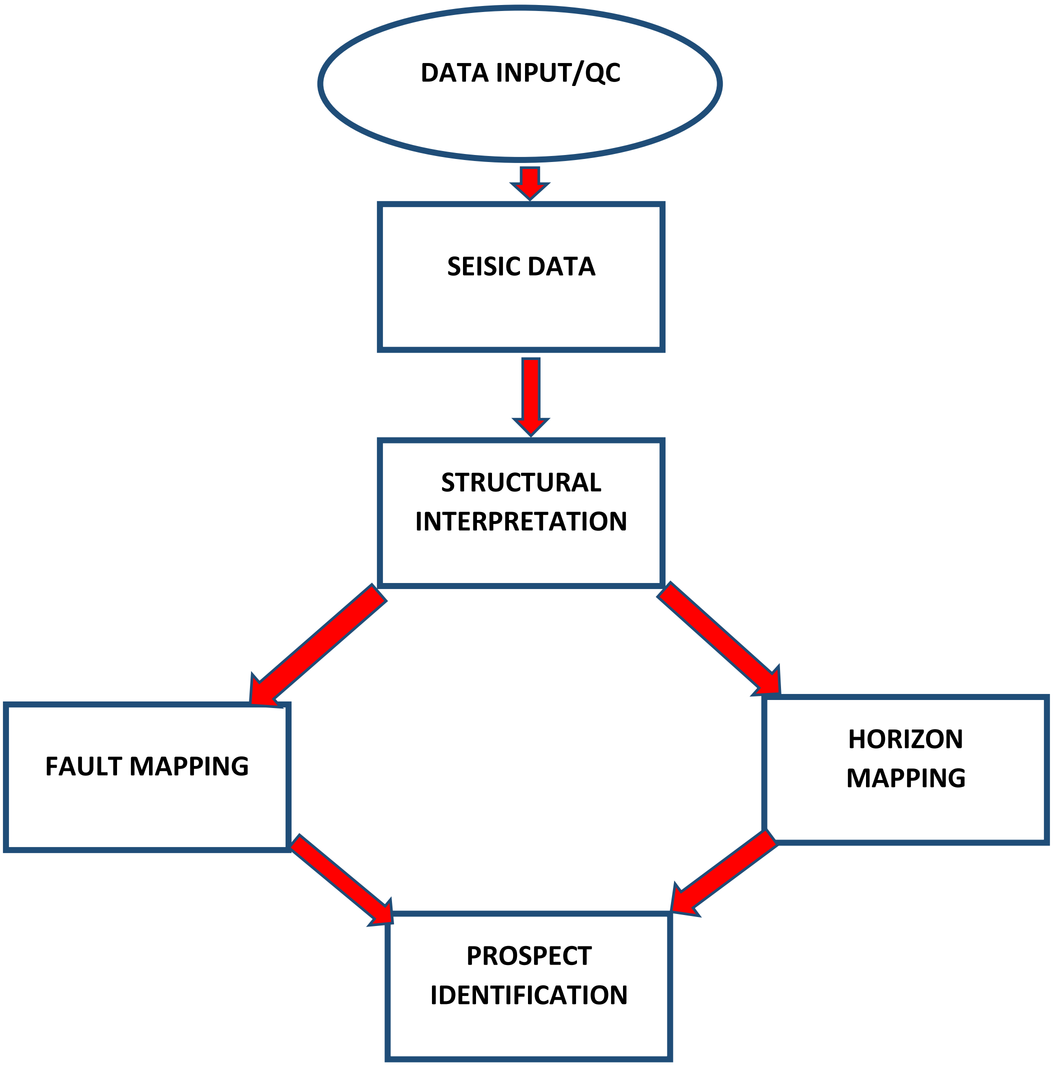


Figure 6: Interpretation workflow adopted for the study

V. Presentation Of Result

Eleven (11) faults (Table 1) were interpreted; fault 2 and 3 were extensive and represent a back to back fault (Figure 7). They are also regional growth fault. Fault 5, 4, and 6 are synthetic faults that dips basin ward (SE), while fault 1 is an antithetic fault that dips landward (NW). Fault 7 is also extensive and a regional growth faults (Figure 8), while fault 10, 11, 12, and 14 are all synthetic faults. A 3D view of the interpreted faults (Figure 9) was generated and displayed together with a variance attribute showing the accurate position of the interpreted faults, and that some of them are regional and extensive while some are not. It also shows that some of the faults dip towards the basin while others do not.

Table 1: Fault classification

Fault	**Fault Type**	**Dip Direction**
F1	Antithetic fault	Northwest
F2	Growth fault	Northwest
F3	Growth fault	Southeast
F4	Synthetic fault	Southeast
F5	Synthetic fault	Southeast
F6	Synthetic fault	Southeast
F7	Growth fault	Southeast
F10	Synthetic fault	Southeast

F11	Synthetic fault	Southeast
F12	Synthetic fault	Southeast
F14	Synthetic fault	Southeast

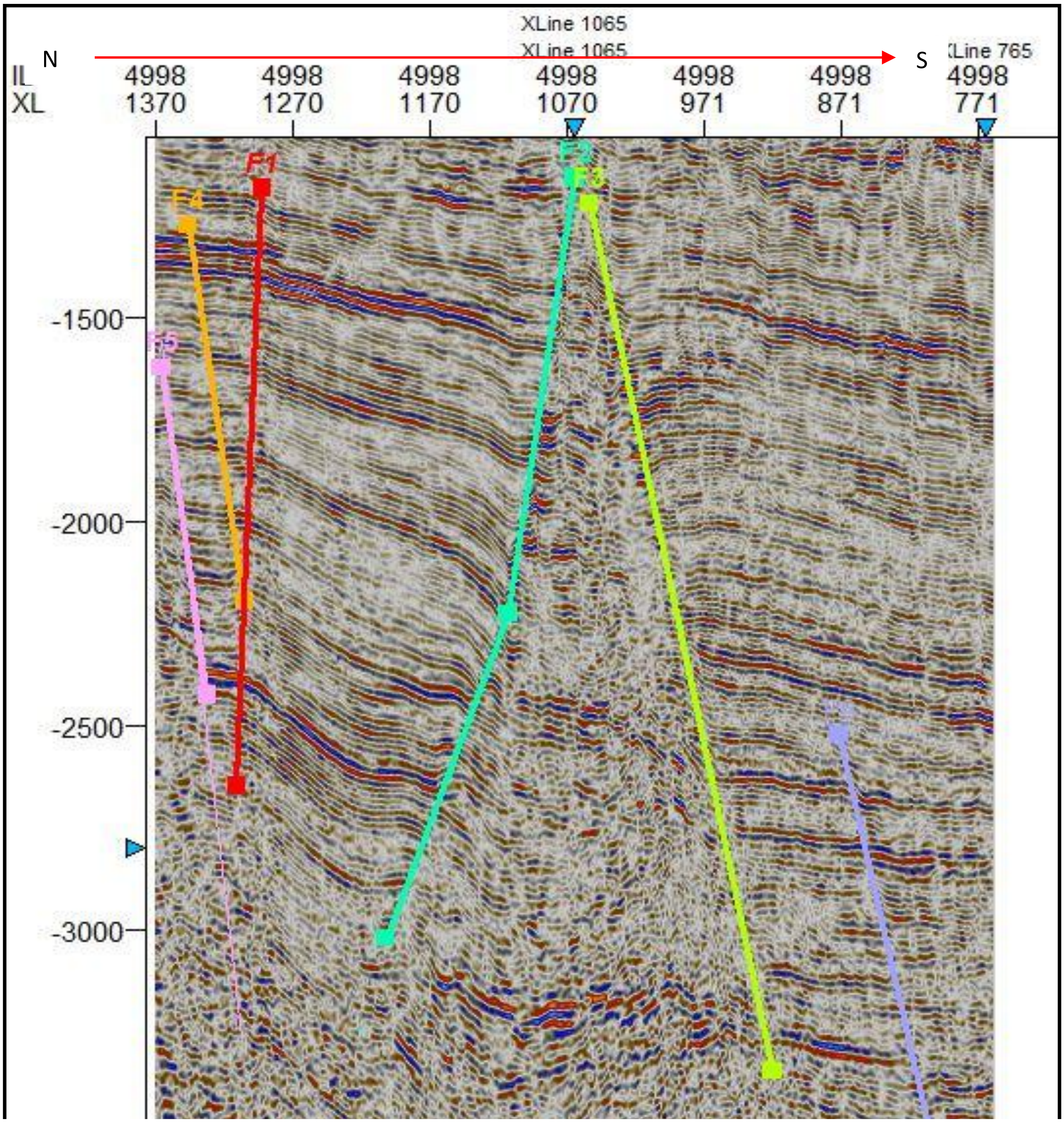


Figure 7: Seismic dip line 4728 showing growth faults, synthetic and antithetic faults as well as back to back fault.

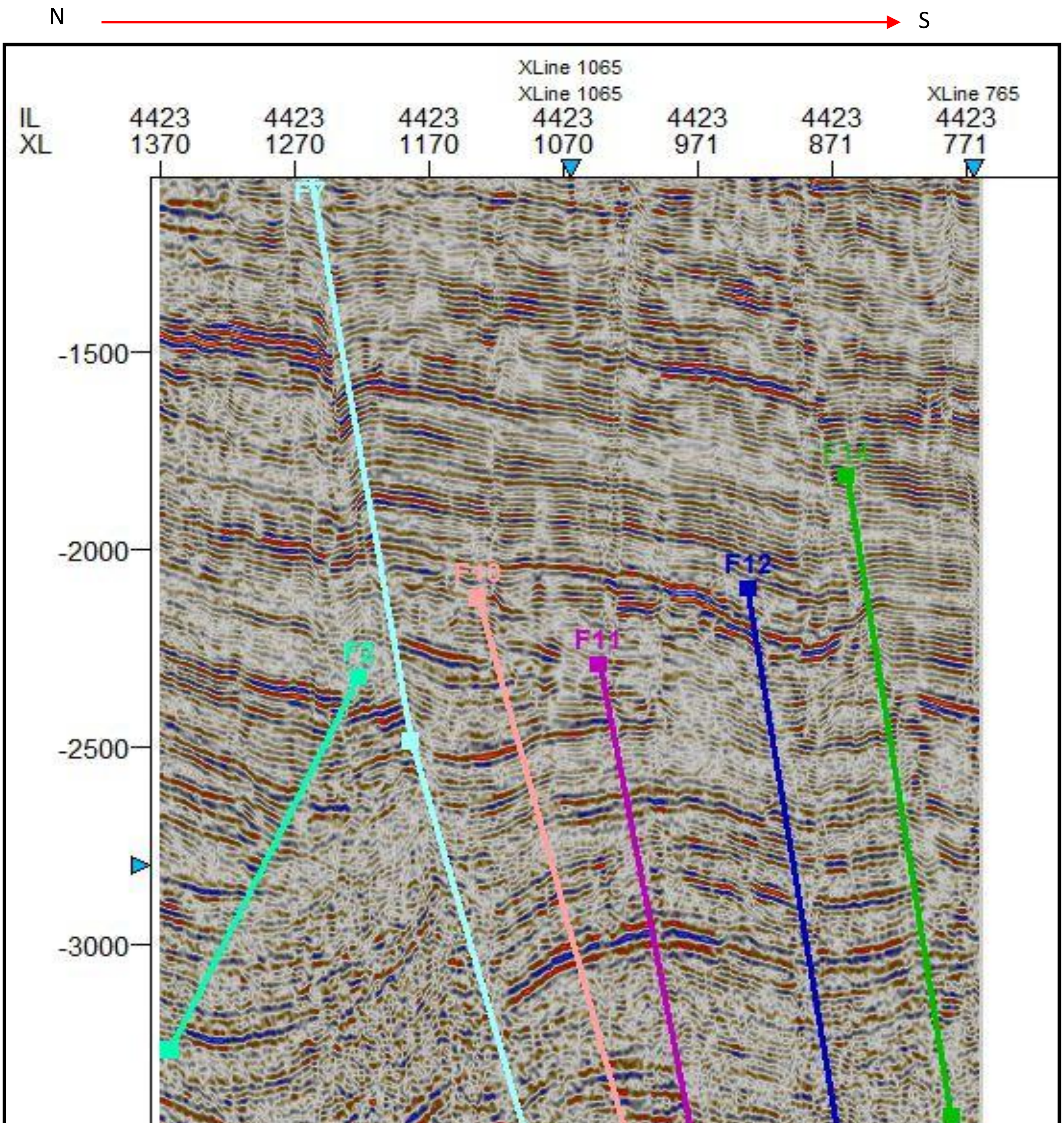


Figure 8: Seismic dip line 4728 showing growth faults, synthetic and antithetic faults

All interpreted faults had the hanging walls moved down relative to the foot wall. The faults types and corresponding dip directions are shown in Table 1. Five seismic horizons were mapped and designated as S2, S3, S4, S7 and S9 (Figure 10). These horizons are indications of top reservoir sands obtained from interpreted well logs, which could be associated with both oil and gas with/without water contact. Subsequently, 3D view of the mapped horizons showing as grid lines and 3D view of the interpreted surface in time domain (Figure 11) and for each horizons (Figure 12) were generated across mapped/picked faults (Fault-sticks) and horizon line. Furthermore, based on the interpreted faults and seismic horizons, results show that several fault assisted closures abound in the study area, are potential sites for probable hydrocarbon accumulation.

VI. Discussion

Structural evaluation of a 3D seismic data from *SUZ*-Field in the central swamp depobelt of the Niger Delta basin has been attempted. The study revealed that the field is comprised of both hanging wall/footwall fault assisted closures situated mostly to west and central parts of the section, with seven prominent synthetic (F4, F5, F6, F10, F11, F12, and 13) faults, three regional growth (F2, F3 and F7) faults and one antithetic (F1) faults.

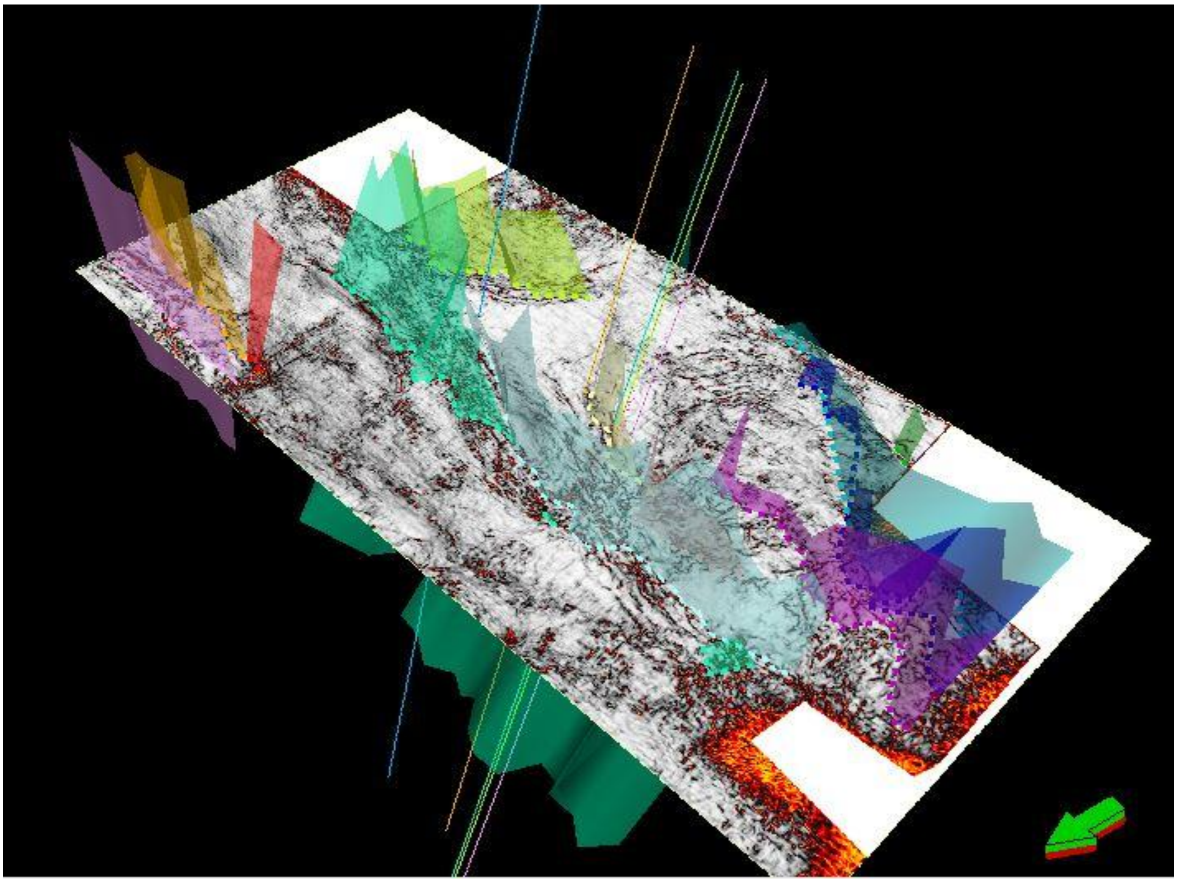


Figure 9: A 3D view of the interpreted faults displayed together with a variance attribute shows the accurate position of the interpreted faults

The synthetic faults trend NW-SE and dips southeastward, while the antithetic fault trend SE-NW and dips Northwestward. The fault closures are characterized by high amplitude reflection events indicative of probable hydrocarbon accumulation. Fairly high amplitudes and strong reflection strength are characteristic of the fault boundaries in the field. These are possible indications of the smearing of the faults and sealing of the reservoirs by clays or shales, which is adequate for trapping hydrocarbons within these fault closures. These revelations suggest that both gas and oil may be present in the field. The study delineated five seismic horizons S2, S3, S4, S7 and S9.

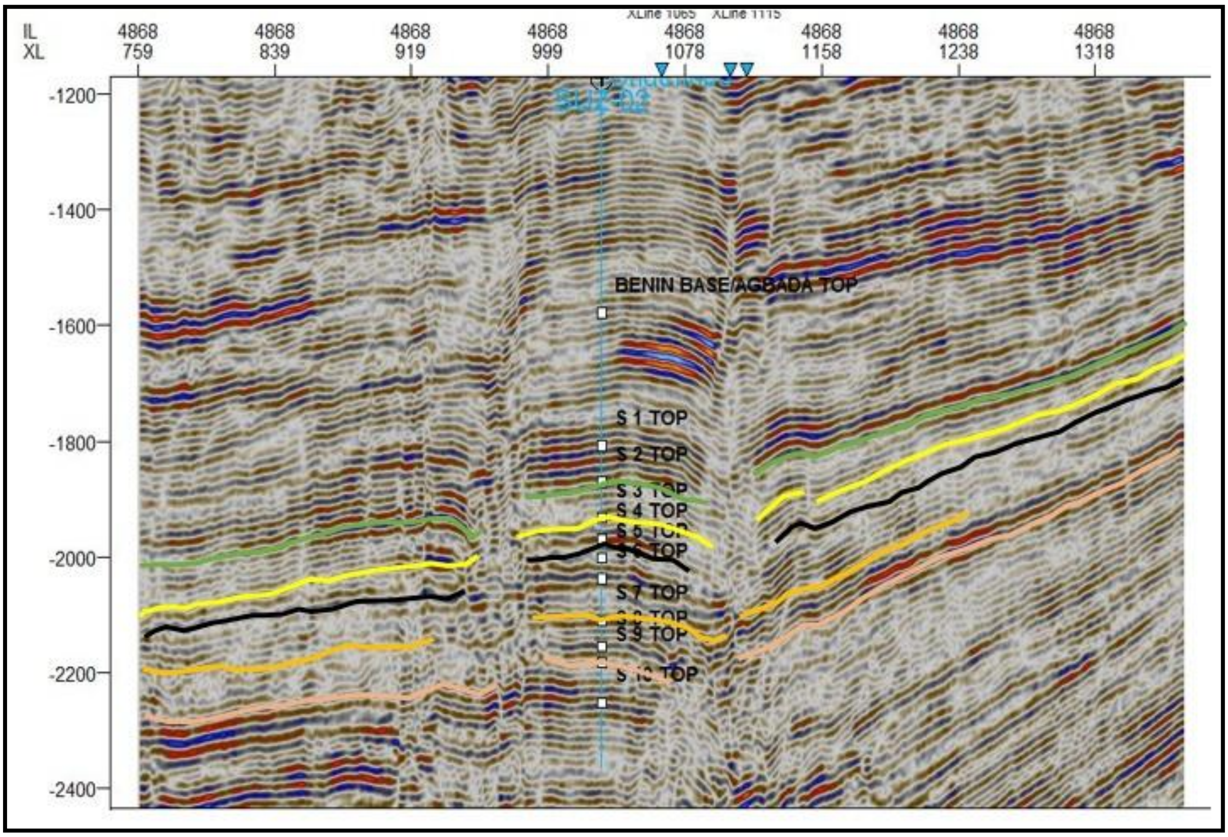


Figure 10: Seismic dip line 4868 showing the five interpreted horizons

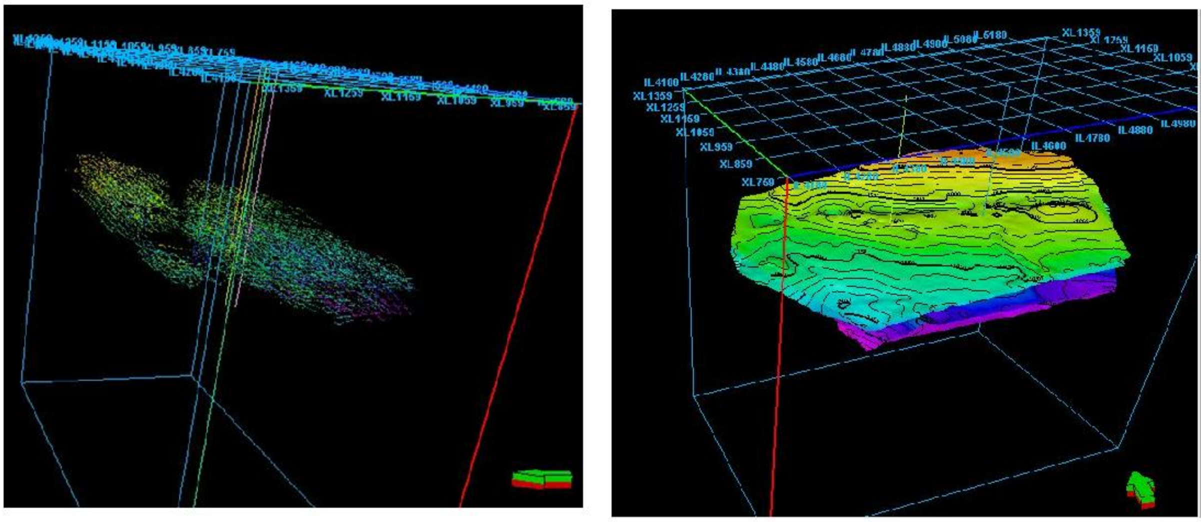


Figure11: On the left is 3D view of the mapped horizons showing as grid lines. While on the right is the 3D view of the interpreted surface in time domain.

All mapped horizons are deeply buried and are fault truncated and have good fault closure (Figure 12) for hydrocarbon trapping.

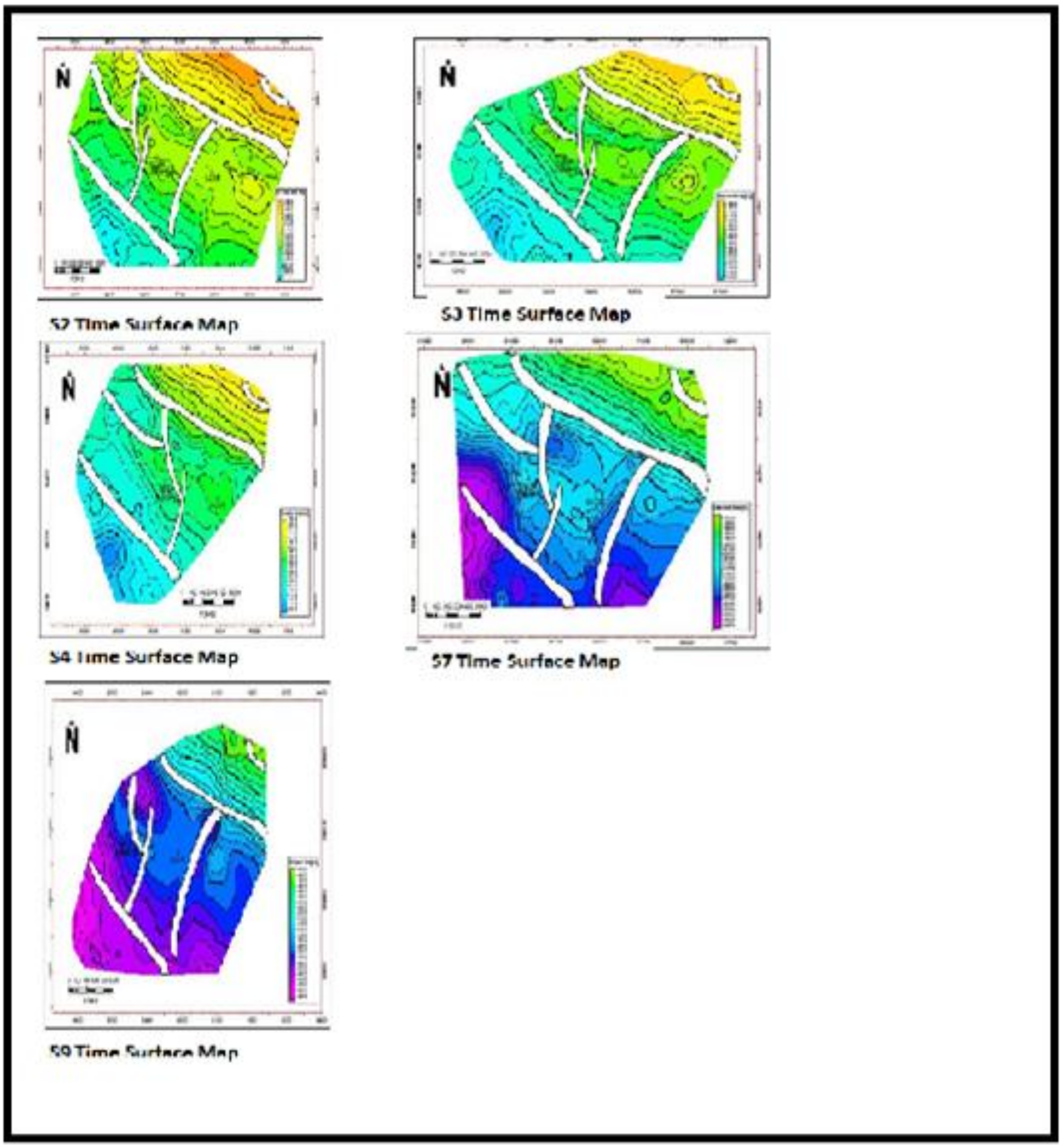


Figure 12: Time surface of S2, S3, S4, S7 and S9 reservoirs (the white lines indicate faults)

The major prospect is delineated along the seismic horizons S2 and S9 characterized by reflections with moderate-strong reflection strength, medium-high amplitude, parallel-sub parallel-wavy and chaotic with good reflection continuity. This continuity in reflection suggests widespread and uniform deposition along the strike direction. Moderate-strong reflection strength implies a moderate variation in acoustic impedance contrast in the lithofacies, whereas medium-high amplitude indicates thick sand body with inter-bedding shales (Figure 10), characteristic of a hydrocarbon reservoir in the Niger Delta basin. The study area is a promising field with good structural framework for hydrocarbon trapping and accumulation. The majority of the faults in the field constitute the main structural trap for hydrocarbon accumulation. Thick reservoir sands with inter-bedded clays/shales within the fault bound closures characterize the field. The interbedded shales serve as good cap rocks to prevent vertical migration and seepage of hydrocarbons into overlaying sediment layers. The prospects for hydrocarbon is high, however, more detailed analysis should be carried out.

VII. Conclusion

A structural evaluation of a 3D seismic data have been presented along inline 4998 over a *SUZ*-Field in the Central Swamp depo-belt of the Niger Delta basin. The *SUZ*-field is a promising prospect with good structural frame work for hydrocarbon accumulations. Seven synthetic, one antithetic, three growth faults and five seismic horizons were interpreted in the section. The seismic horizons have fault assisted hanging wall/ footwall closures from the time surface maps with distinctive high amplitude reflection events, which are indicative of probable hydrocarbon accumulation. The horizons are characterized by moderate to strong reflection strength, medium to high amplitudes and good reflection continuity. These suggests wide spread and uniform deposition of clastic sediments with thick sand facies and inter-bedding shales, which is characteristic of hydrocarbon reservoirs in the Niger Delta basin. The prospects for hydrocarbon in the field are high which can be explored.

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