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Investigation of Hydrocarbon Accumulation in Pearl Field, Niger Delta Offshore: Using 3D Seismic and Well Log Interpretation

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Abstract

Geophysical data are vital for understanding the geological structures within an area for hydrocarbon trapping potential. Well-log suites and 3D seismic data were employed to assess the subsurface structure of Pearl Field Offshore, Niger Delta Basin. The 3D seismic and well-logs were examined to map structures responsible for hydrocarbon accumulation. This involves fault interpretation and horizon interpretation. This study revealed that the field was controlled by the growth faults and rollover anticlines structures. Twelve (12) faults were identified and mapped on seismic sections across the entire field, where two (2) are major growth faults (F2 and F3), four (4) are synthetics faults (F4, F5, F6 and F7), and five are antithetic faults (F8, F9, F10, F11 and F12). Fault F2 (yellow colour) cuts through the entire mapped area. Fault F3 (green colour) trends southwest to the middle of the seismic survey. Hence, Faults F2 and F3 are predominantly the active major structure building faults (MSBF). The synthetics and antithetic were interpreted as minor faults. Reservoir sands were delineated from the well-logs using gamma-ray for the lithology identification and resistivity-logs for the fluid identification. Horizons were mapped across the seismic section. Hence, the result shows that the presence of faults is an indication that there is potential element that is responsible for hydrocarbon accumulation in the Pearl Field. The major faults block E and F were interpreted as the major structure building faults (MSBF) responsible for major structural trap at the western part of the survey. This also revealed that growth faults and rollover anticlines are the highly faulted structural elements responsible for hydrocarbon accumulation. These closures are displayed to detect potential hydrocarbon traps on the down-thrown side of fault blocks E and F.

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Introduction

The seismic approach is a significant geophysical method used to investigate subsurface structural styles and layers in the subsurface. Seismic interpretation helps to characterize underground geological structures and lithology with high precision (Jadoon *et al.,* 1994). Seismic data analysis help distinguish rocks that have hydrocarbon and rocks that do not have hydrocarbons. Seismic data interpretation will provide relevant structural and geological information to other researchers. A seismic study is undoubtedly an efficient tool for hydrocarbon accumulation; it is significance in identifying prospects, predicting source rocks, seals and potential reservoir traps (Nton, and Esan, 2010). The major motive of structural interpretation is to use well and seismic section to delineate the subsurface structures that are potential hydrocarbon accumulation areas. The mapping of faults gives valuable information on how fluids flow and the connectivity of the fluid within reservoirs. Faults as a geological structure can have significant effects on the permeability of reservoirs, and also have impact on the productivity and efficiency of the reservoir (Santosh *et al,* 2013). Hydrocarbons are trapped mainly in rollover anticlines associated with syn-sedimentary growth faults. Evamy *et al.* (1978) related the physical properties of hydrocarbons, particularly to source rock variation and geo-temperature. They concluded that late migration occurred near the attainment of present day overburden coinciding with source rock maturity. Seismic attribute analysis helps to identify structural features; it also helps to increase the chances of success and development of new prospect areas

(Sheriff, 1997). The bright spot is a valuable mapping tool that allows visualization identification of features related to the hydrocarbons directly on seismic traces. Seismic-to-well tie is the best way to tie seismic data back to ground truth by comparison with well log data using synthetic seismogram; is also widely used for seismic interpretation. Seismic-to-well tie helps to produce wavelet for inversion for reservoir properties (Ziolkowski, *et al.*, 1999). The value of the seismic-to-well tie depends on the seismic data quality, well data and the time/depth relationship. The usual way to tie well information to seismic data in the depth domain is to convert them to time, tie them and convert them back to depth. Accurate seismic-to-well ties are fundamental to the interpretation of surface seismic data. A statement of seismic-to-well tie accuracy is essential to any attempt to quantify uncertainty in seismic lithological interpretation. Hence, seismic data and well log data are used to indicate favourable structural elements and understand the economic important of the PEARL Field for hydrocarbon accumulation.

Geology of The Study Area

The study area is situated within latitudes 3^0 and 6^0 N and longitude 5^0 and 8^0 E. Figure 1 shows geological maps of Niger Delta's present day structural settings. The structural settings are rollover anticlines, growth faults, back to back faults, collapse crest faults and shale diapirs. The area extent of the location is about 75000 km^2 with a clastic fill of about 12000 m. The Niger Delta depositional cycles are subdivided into three diachronous litho-stratigraphic units Akata, Agbada and Benin Formation Figure 1. The Akata Formation, which includes marine shale is the oldest units and forms the base sequence in each depobelt and has a stratigraphic thickness of over 6000 m of mainly marine shale which is the major hydrocarbon source rock. The lithofacies comprise shales, clays, and silts at the known base of the delta sequence. The marine shale sequence is typically over-pressured (Merki, 1972).

The Agbada Formation, a paralic sequence, is characterized by the alternation of sand bodies, clay and thicknesses, representing cyclic sequences of offlap units. This alternation provides multiple reservoir-seal couplets. The Agbada Formation forms the hydrocarbon-prospective sequence in the Niger Delta. This syn-sedimentary growth faulting which is paralic sequence form contains the bulk oil accumulation in the Niger Delta. Due to its marine shales, the sequence is present in all depobelts and a stratigraphic thickness of more than 4500 m.

The Benin Formation has massive continental sandstones and is the uppermost part of the sequence. It was deposited in alluvial form as deltaic deposition into a new depobelt, has a stratigraphic thickness of 2100 m (Merki, 1972).

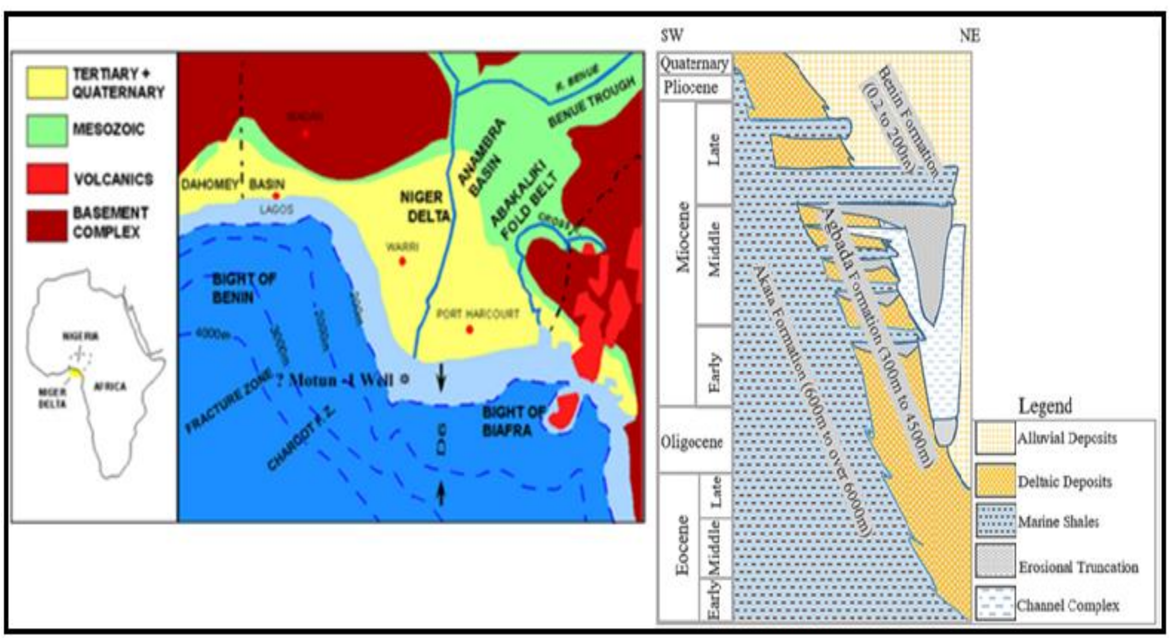

Figure 1: Geological map of Niger Delta Basin showing present day structural settings (Ajisafe and Ako, 2013 and Niger Delta litho-stratigraphic successions (Reijers, 1997).

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Structural Patterns of the Niger Delta

The occurrence of syn-sedimentary faults, which deforms the delta beneath the Benin Formation, presents a very striking structural feature. The different types of structures are: non-faulted anticline rollover structures, faulted rollover anticline with multiple growth faults, or anticline faults and complicated collapse crest structures, (Evamy *et al.*, 1978). These syn-sedimentary faults are known as growth faults while the anticlines associated with them are also known as rollover anticlines (Figure 2). According to Whiteman (2012), they are called growth faults because they are frequently initiated around local depocenters and grow during sedimentation, thereby allowing a greater amount of sediment to accumulate in the down thrown block than the up thrown block. These growth faults affect the Agbada and the Akata formations and die below the Benin Formation. According to Doust and Omatsola (1990), the magnitude of throws on growth faults bounding depobelts is such that much of the parallic succession on the downthrown side is younger than the upthrown side. Growth faults present a migratory path for hydrocarbons generated in the Akata and Agbada formations, enabling them to migrate and accumulate in the reservoir sands. Growth faults also act as seals to migration. When fault throw exceeds the sand thickness, the fault zone serves as a seal but this depends on the amount of shale smeared into the fault plane. Growth fault and rollover anticlines always occur in association, and these structures, make known that petroleum has formed in Agbada reservoir sands.

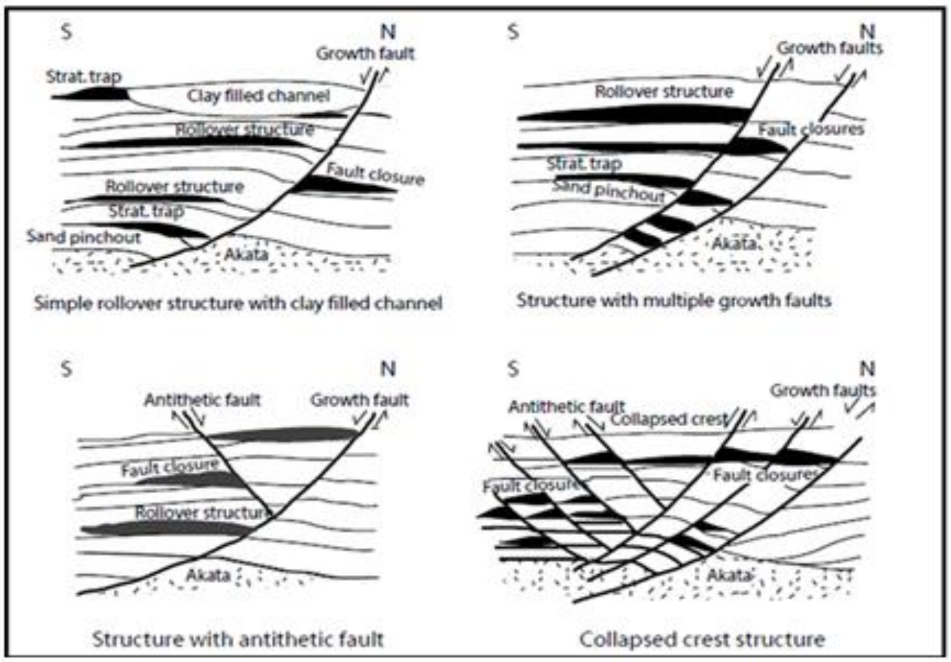

Figure 2: Showing examples of Niger Delta field structures and associated traps (Doust and Omatsola, 1990, Stacher, 1995)

Hydrocarbon Trap

Hydrocarbon traps are formed where permeable reservoir rocks are covered by rocks with low permeability that are capable of preventing the hydrocarbons from further upward migration. If the upward loss of hydrocarbons is less than the supply of hydrocarbons from the source rocks to the reservoir, hydrocarbons may still accumulate. A trap is the element that holds the oil and gas in place in a pool. Trap means any combination of rock structure and permeable and impermeable rocks that will keep oil and gas from escaping. Some petroleum reservoirs fill the trap so if any additional oil or gas were added it would spill out around the lower edge. Hence the lower boundary of the reservoir is, either wholly or partly. An impermeable rock layer, called the cap rock, prevents the upward or lateral escape of petroleum (Milton and Bertram, 1992). Such a part of the trap is called the petroleum reservoir. Hence, water initially present in a reservoir gets displaced downward with oil and gas accumulation. This structurally lowest point in a trap that can retain hydrocarbon is called the spill point. While the height to the crest of a structure above the spill point of a trap is called closure (Figure

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3). A reservoir rock and a seal are important factors used by a trap to store hydrocarbons, and impede or stop migration out of the reservoir (Milton and Bertram, 1992).

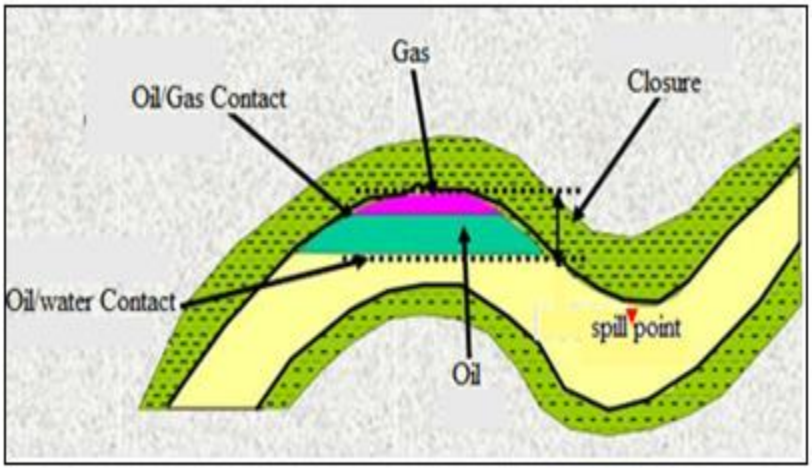

Figure 3: Anticlinal structural traps with oil-water contact and oil-gas contact (Knut Bjorlykke, 1989).

Necessary Conditions for Hydrocarbon Accumulation

Source Rocks

Source rock is a sedimentary rock containing organic material, which produced liquid or gaseous hydrocarbons under heat, time, and pressure (Evamy et al., 1978), (Figure 4). Source rocks are usually shale or limestone (sedimentary rocks). The organic richness of a rock is usually expressed as the total organic carbon content (TOC). It is apparent from the above definitions that a source rock to be effective must attain a certain level of maturation to generate hydrocarbons. Moreover, before a source rock can be effective, it has to be a good potential source rock that is; it has to be sufficiently organically rich enough to generate and expel hydrocarbons (Ronov, 1985).The categories of source rocks are; possible source rock, potential source rock, effective source rock, spent source rock and relic effective source rock. .

Characterization of Source Rocks

1. It must have the quantity of organic matter capable of generating petroleum. The organic matter is an important factor for evaluating the source rock potentiality and has important influence on the nature of the hydrocarbon products (Waples, 1994).
2. It must have quality capable of yielding moveable hydrocarbons which is measured by determining the types of kerogen contained in the organic matter.
3. Thermal maturity: The organic matter's character influence hydrocarbon generation interpretation. For this reason, when assessing generation, one has to be aware of the effects of maturation on the organic matter.

Reservoir Rocks

A reservoir is a subsurface volume of porous and permeable rock with both storage capacity and the ability to allow fluids to flow through it. (Evamy *et al.*, 1978), define reservoir rock as one with porosity and permeability that allows it to contain a significant amount of extractable hydrocarbon. This means it has tiny holes through which oil can flow. Reservoir rocks must be porous, because hydrocarbon can only occur in pores. The main reservoirs are sandstone and unconsolidated sands. The reservoir within a trap provides the storage space for the hydrocarbons. This requires adequate porosity within the reservoir interval. The reservoir must be capable of transmitting and exchanging fluids.

Seals Analysis

A seal is an impermeable bed capping the reservoir rocks in a trap. A seal is a rock that forms a barrier or cap above and around reservoir rock forming a trap such that fluids cannot migrate beyond the reservoir. Without effective seals, hydrocarbons will migrate out of the reservoir rock with time and the trap will lack viability. Although thicker seals are usually more effective for hydrocarbon accumulation, if a seal has low permeability, is ductile, laterally continuous, and has high capillary entry pressures, it will still be very effective regardless of its thickness. The primary seal rock in the Niger Delta is the inter-bedded shale, which provides three types of seals; clay smears along faults, inter-bedded and vertical seals (Aizebeokhai and Olayinka, 2011).

Migration

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Migration is the movement of generated hydrocarbons from the source rock to the reservoir rock in a trap through conduits such as permeable beds, fractures, and faults. Primary migration is the movement of generated hydrocarbons out of the source rock into a more permeable conduit. Secondary migration is the movement of petroleum through the conduit into a reservoir in a trap. Tertiary migration occurs when petroleum moves from one trap to another (Peters *et al.,* 2012). Accumulation is the end of migration, where hydrocarbons have reached a trap and are stored in the reservoir.

Trap Analysis

A trap consists of a geometric arrangement of permeable and less-permeable rocks that can allow hydrocarbons to accumulate when combined with the physical and chemical properties of subsurface fluids. A trap may or may not contain oil or gas. Accumulations, or pools, are traps that contain oil or gas. Trap reservoir helps in the storage for accumulating of hydrocarbons and can transmit hydrocarbons. A trap seal is an impediment or barrier that interferes with hydrocarbon migration from the reservoir. Trap fluids are the physical and chemical contrasts especially differences in miscibility, solubility, and density between the common reservoir fluids (primarily water, gas, and oil) that allow hydrocarbons to migrate, segregate, and concentrate in the sealed reservoir.

Fault Analysis

A fault trap occurs when the formations on either side of the fault have been moved into a position preventing further petroleum migration. Faults can be important in providing seals for a trap, and fault leak is a common trap limitation. Faults may be considered seals where the fault planes comprise impermeable rocks such as clays or cemented materials at the walls in the throw interval. They can behave as a seal or a conduit for hydrocarbon transportation to a trap. If a fault trap has a large enough volume to store oil and gas, drilling and production can become economically viable (Allan, 1989).

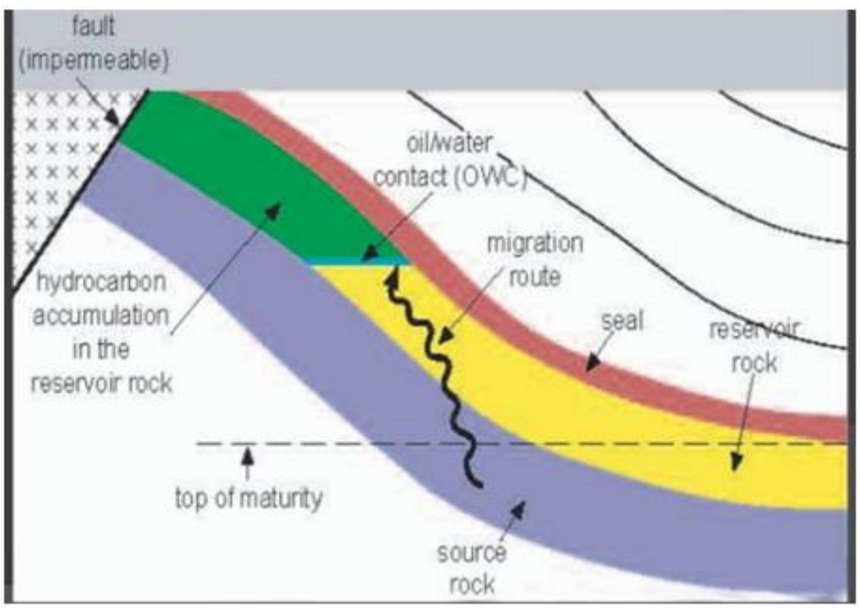

Figure 4: Hydrocarbon accumulations – Migration pathways Bjorlykke, 1989).

Materials and Methods

The data used for this research work were provided by Department of Petroleum Resource (DPR). The data comprised of 3-D seismic data (SEG-Y format), check shot data, base map of the study area and suit of well logs including: gamma ray, resistivity log and density logs. All of the data were imported into an interactive geophysical workstation. The seismic base map helped to understand the geology of the study area as shown in Figure 5. The seismic lines are cross-lines shot parallel to the dip direction and in-lines shot parallel to the strike direction. The interpretation was done using petrel's (2009) software.

The Pearl field structure of the study area was delineated using 3D seismic data and well logs data and this was done in order to obtain geological features in the study area. The geological features are fault interpretations, horizon interpretation, attribute generation and well correlation. The gamma-ray log and resistivity log were used for lithology

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identification between sand and shale and the low gamma-ray indicates sand formation, and high gamma-ray indicates shale unit. A resistivity log was used to differentiate between water and hydrocarbon in the pores of the delineated sand reservoirs of hydrocarbons reservoirs is found within sand units. The check shot data for well 0X1 was used for the seismic-to-well tie of the hydrocarbon reservoirs. This tie formed the first step in picking events, to the tops of the sands for interpretation. Horizons were mapped to generate time structural maps using the velocity function. Structural cross-sections were drawn through all the wells (Pearl 1-4) and well X01 depict the lateral variations of the horizons within the limits of the data provided. The horizon identified was tracked on reflection to produce the time structure maps. Depth structure maps were produced from the time structure maps using the velocity information derived from check shot data. Major and minor faults networks were then identified based mainly on the abrupt termination of reflection events and marked on cross lines. Also, the throws of the major faults were also determined, and this was used to determine the sealing potential of the faults. Surface seismic attributes were employed to enhance the fault interpretation. Hence, integrating seismic and well log, the following processes were used: data quality check loading, well-log correlation, lithology identification, and hydrocarbon bearing zone these were done to determine hydrocarbon accumulation in the field. Figure 5 also shows the flow chart for the study.

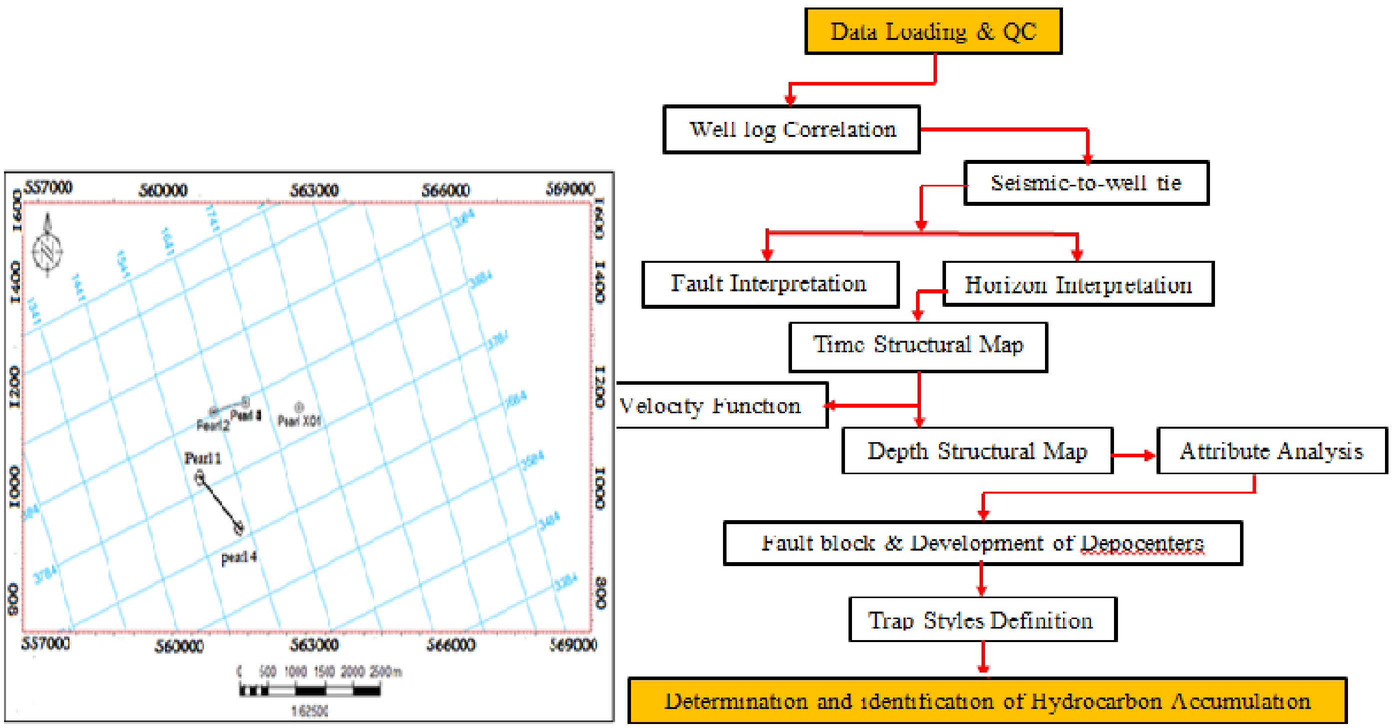

Figure 5: Seismic Base Map of the study area and workflow chart for the study.

Seismic Data Acquisition and Processing

The seismic method has been greatly improved in the areas of data acquisition. In acquiring data, a ship tows one energy source fastened parallel with one towed seismic receiver line. The receiver lines are called steamer contained a number of hydrophones. The vessel moves along and fires a shot, with reflections recorded by the hydrophone. Since the numbers of parallel sources and streamers are towed at the same lines/time, some parallel lines recorded simultaneously (Figure 6). Also, if many closely spaced parallel lines are recorded, a 3D data volume is recorded.

Seismic data processing aims to obtain an image of the sedimentary basins in the earth's interior using waves generated by "artificial" earthquakes. Data acquired are prepared for processing by the field party itself and then it is send to the processing center. Processing is required because the data collected from the field are not true representation of the subsurface; hence nothing of importance can be inferred from it. The important of seismic data processing information recorded in the field are used for geological interpretation. Through processing we enhanced the signal to noise ratio, removing the seismic impulse from the trace and repositioning the reflectors to its

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true location, thereby making it into a more palatable form. The velocities of seismic waves in the earth can be derived from seismic data or measured in wells, and they are used to convert the known reflection times into estimated reflector depth. Analysis of recorded seismic signals is to reduce unwanted noise and create an image of the subsurface to enable geological interpretation, and eventually obtain properties of the subsurface. See table 1.

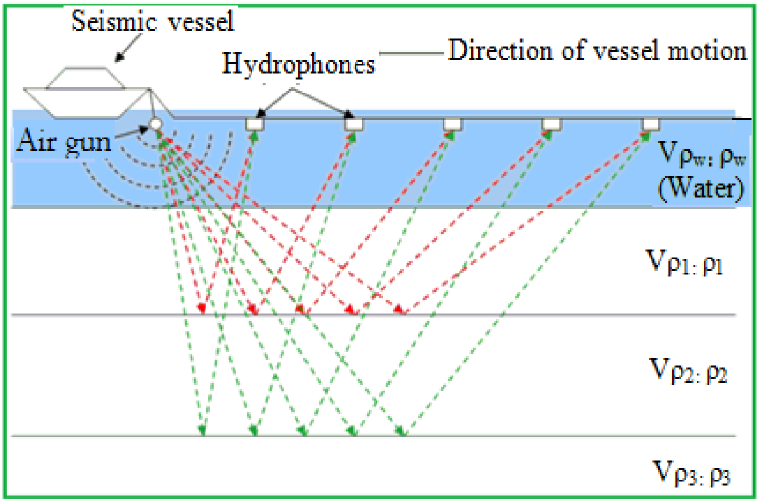

Figure 6: showing marine towed steamer seismic survey. The red colour is a ray path to the first reflector and the green colour is a to second reflector (Dentith and Mudge, 2014)

Table 1: Seismic Data Acquisition and Processing

ACQUISITION OF PARAMETERS USED	MEASUREMENTS
Recording year	2020 / 2021
Energy / Seismic Source	Air gun
Gun volume	5.5
Shot interval	23m
Shot depth	5m
Field record length	18s
Spread pattern	Split
Shot-receiver near offset	30m
Shot-receiver Far offset	1011m
Number of channel / line	18
Record format	SEG Y
Firing interval	0.23m
Precision of	< 1m
Source offset	2m perpendicular to survey lines
Record filter	8-150HZ
Survey geometry	Fixed
Actual number of traces	312
Channel interval	25
Hydrophone spreading	10m
Stacks	Minimum of four (4)
Sampling method	0.5ms
Sampling rate	1ms
Sample interval recorded	2m
Number of receiver lines (steamer)	35
Receiver line interval	2.0m
Source line interval	2.0m
In-line source spacing	0.25m
Cross-line source spacing	0.25m
Actual number of source point	206
Channel spacing	0.35m
Air gun pressure	1.4×10^7 pa (2000psi)
Frequency of hydrophone	39ms

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Results and Interpretation

Seismic Structural Analysis

Structural interpretation was used to determine structural element that is responsible for accumulation of hydrocarbon in the PEARL Field. The field identified twelve faults and labeled as fault (F1, F2, F3, F4, F5, F6, F7, F8, F9, F10, F11 and F12) showing the identified growth faults of different orientations mapped across the entire seismic survey. Major growth faults F2 and F3 were identified in the field on inline 3662. Fault F1 (blue color) is an older inactive fault located offshore which must have been active in the past. Fault F2 (yellow color) cuts through the entire mapped area and Fault F3 (green color) trends south west to the middle of the survey (Figure 7). Hence, Faults F2 and F3 are predominantly the active major structure building faults (MSBF). The synthetics faults are F4, F5, F6, and F7 and antithetic faults are F8, F9, F10, F11 and F12. The synthetics and antithetic faults were interpreted as the minor faults and no visible growth is observed. This shows that the structural patterns are Niger Delta tectonic setting with the presence of normal fault, listric concave in nature. The growth faults have well developed rollover anticlinal structures, extensive across the field. Structural closures identified as rollover anticlines were formed due to the deformation of the sediments deposited at the downthrown block of faults F2, and F3 (Figure 8). The rollover anticline structures, bounded by the closure of two major faults F2 and F3 were displayed on the time/depth structure maps suggests possible hydrocarbon accumulation at the downthrown side. The generated time structure maps were converted to depth structure maps by using velocity information from the check shot data (Figure 9). The depth structural map has contour lines vary from 900 ms to 1336 ms with corresponding high on the time structural maps. On this map, the horizon runs across the field from east to west, making it have reflections corresponding from 950 ms to 1300 ms and marking the top of sand. The maps showed the major active faults F2 and F3 that formed the closure for the trapping of hydrocarbon accumulation (Figure 9). This is because the crest is structurally high, thus enabling hydrocarbon accumulation and is a region of interest for hydrocarbon exploration. This also confirms the validity of the existing interpretation.

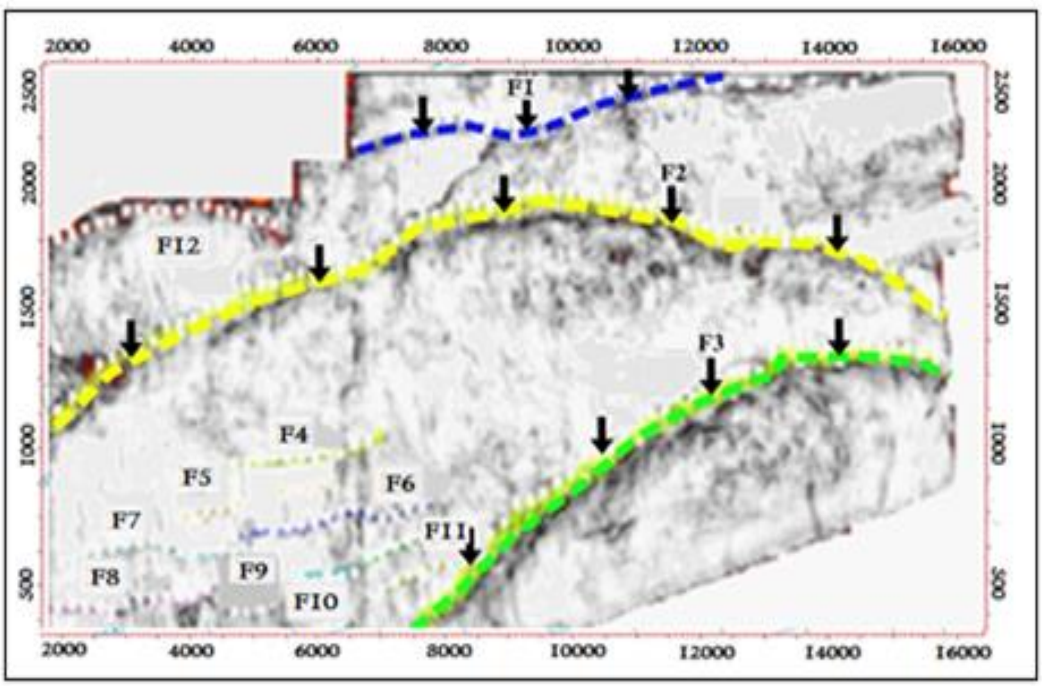

Figure 7: Showing interpreted Structural framework of PEARL Field

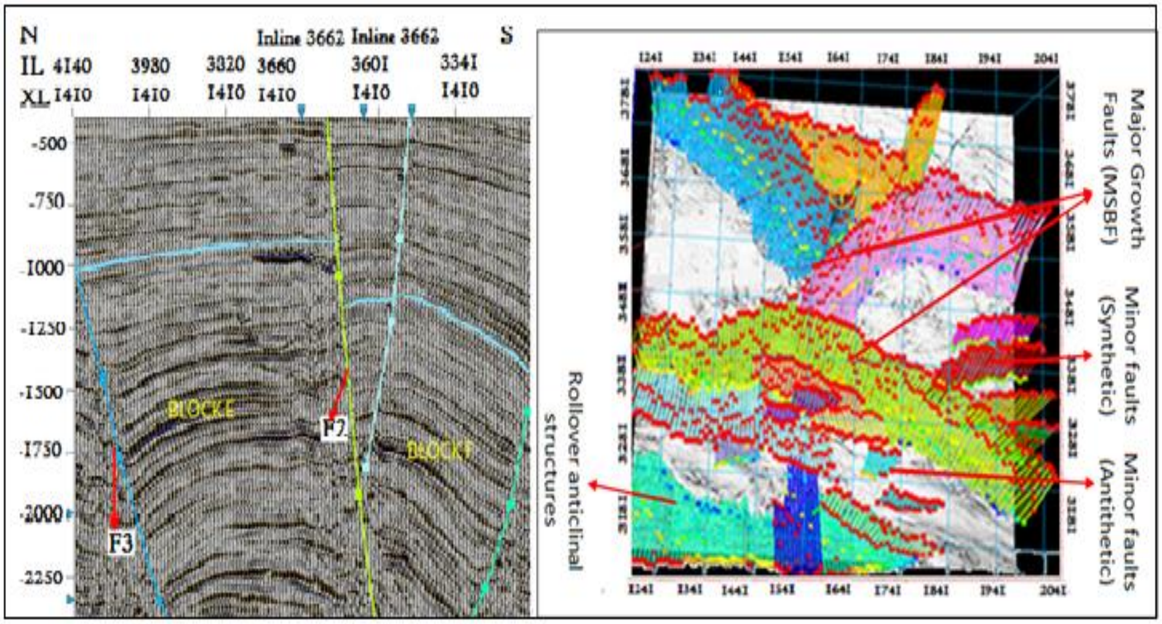

Figure 8: showing fault block E and F as the important blocks contain structural trapping capacities for hydrocarbon accumulation and 3D Major Structure Building Faults (MSBF), Minor faults (synthetics and antithetic) and Rollover anticlinal structure

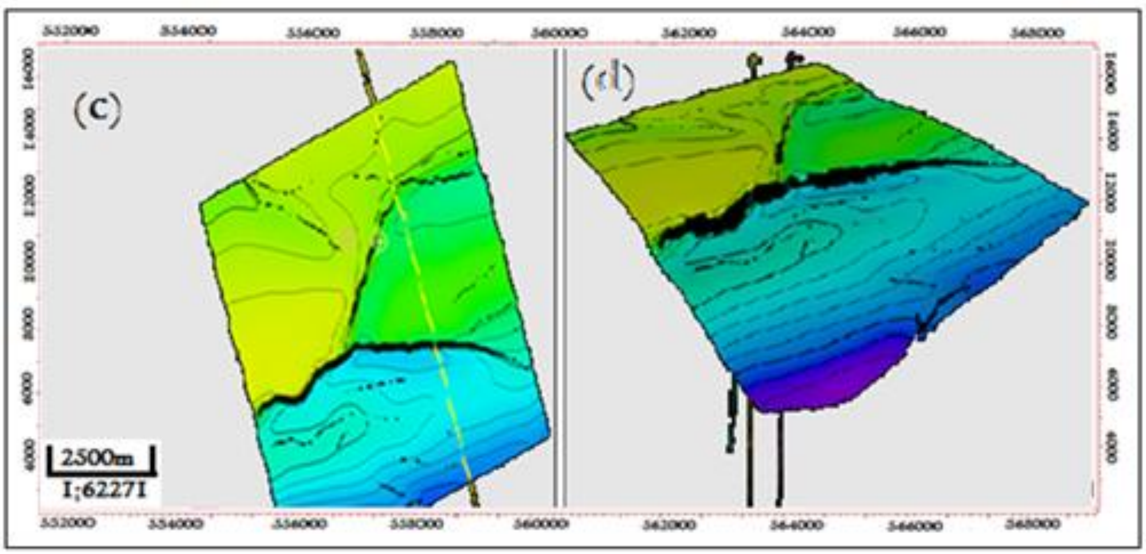

Figure 9: showing Depth structure maps for horizon (2D view) and interpreted well in 3D view on depth structure map.

Growth Fault Geometry

Fault geometry discusses the overall understanding of the deformation of the terrain. It was carried out in 3D seismic volume. The mapped fault networks and geometries are studied on maps to analyses the deformation style. It has various objectives such as; basin formation studies, deformation in hydrocarbon reservoirs etc. Growth faults are syn-depositional extensional faults with two blocks; the upthrow and downthrown block. The upthrow block is the footwall and the downthrown block is the fault plane's hanging wall of the Cazes, (2004). Most deformations occur within the hanging wall. The downthrown block slips downward relative to the upthrown block (Figure 10). This is caused due to the differential load of the overlying sediments. As a result, the sedimentary layers collapse forming synthetic and antithetic normal faults that dip in the same direction or the opposite direction or bend forming rollover anticlines. The 3D geometric arrangement of geological

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structures identified such as faults and horizons were classified as normal, listric faults.

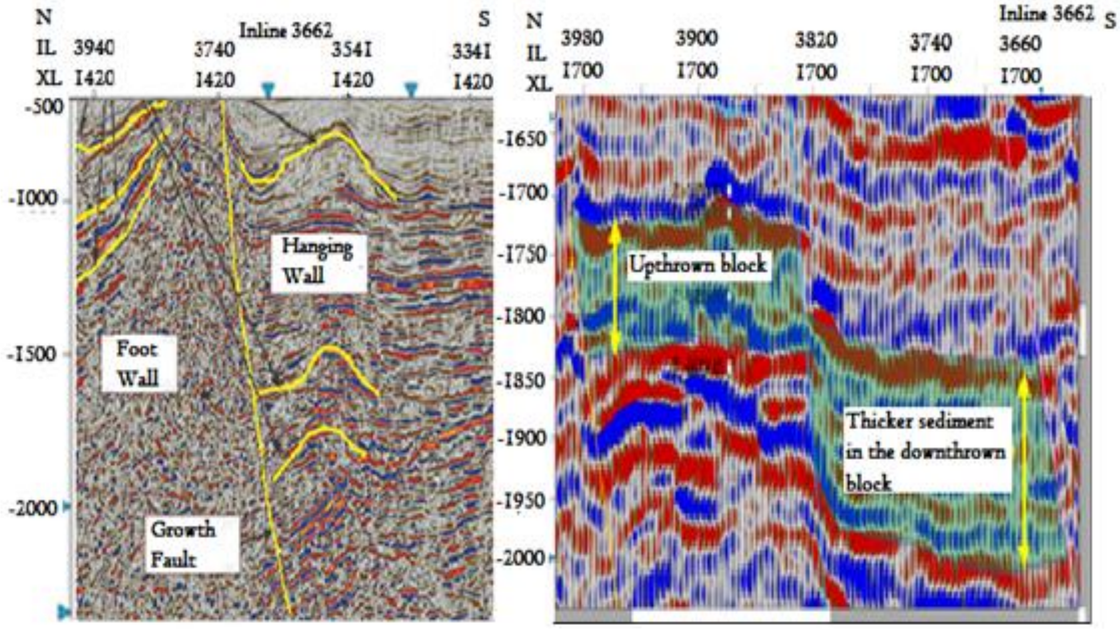

Figure 10: Showing sediment thickness variation and Seismic line showing sedimentary layers, footwall and hanging wall of a growth fault.

Well Log Interpretation

Well-log interpretation involves the determination of a reservoir. The well logs were provided for five wells (Pearl 1, Pearl 2, Pearl 3, Pearl 4 and X01) and well-0X1 has a reasonable depth, showing an outstanding permeability value of 653md (Table 2). The gamma-ray, resistivity log, and density logs were used for the fluids types present, determination of lithology and contacts. Gamma-ray (GR) logs (blue color) were used for the lithology penetrated by the wells, thus the lithology delineated were sand and shale beds. For reservoir areas of interest, the resistivity log (red color) was used to delineate the presence of hydrocarbon; which shows that a high resistivity value indicates hydrocarbon accumulation and a low resistivity value indicates presence of water in the reservoir. These analyses were done on the five wells across the reservoir of interest (well-0X1) in the Pearl Field. The lithology units have lateral continuity of the sand intervals, as evidenced by structural trends. It was deduced that only well-0X1 penetrated the hydrocarbon portion (Figure 11). Table 2 shows that only Well-0X1 has a complete suite of logs needed for this work. Well to seismic correlation mapping was done to tie similar reservoirs across the seismic area. The combination of these has improved the accuracy of identification of structures. Before this, the intercalation of sand and shale in the Agbada formation forms a network of reservoirs overlain by a seal which is a key to hydrocarbon accumulation. Hence, the reservoir is a good quality because it has been predicted on the well log characteristic, indicating the sand sequence.

Seismic to Well Tie Interpretation

According to (White and Simm, 2003) seismic to well tie is the process through which seismic data wavelets are understood and compares seismic data at a well location with log data from the well. Thus, the seismic-to-well tie generated synthetics with compatible signatures with the surface seismic to enable comparison with the seismic at the well location. The comparison resolves differences in velocity and phase, but may be hampered by noise due to the logs and synthetics impaired by borehole conditions. As a result of tailoring the wavelet and synthetic a better tie was achieved. As illustrated in Figure 11, the synthetic seismogram generated from the well log was linked to correspond with seismic event of the seismic section; this was done by considering the reflectivity trace being differential acoustic impedance which when moved down by greater wavelet, it looks similar to reflectivity trace. Based on seismic calibration, the seismogram utilizing density logs with check shot from well 0X1 to ensure that seismic-to-well tie have a good an accurate tie between the events. Vertical discontinuity of reflection was used to trace the fault plane on inline and interpretation was done in accordance with horizon delineated. As a result of seismic shift caused by shallow event, static shift was used to the synthetic to match up with the seismic at Pearl 1490-top and Pearl 1500-base of Pearl 0X1 well log. Therefore, the essence of this tie was to provide more confidence in seismic interpretation (Figure 11).

Table 4.2: Showing wells in Pearl Field as a suite of logs in each well.

Well	GR(API)	RES(Ωm)	NPHI (g/cm^3)	Checkshot(ms)
Pearl-well 1	Yes	Yes	No	Yes
Pearl-well 2	Yes	Yes	Yes	NO
Pearl-well 3	Yes	Yes	No	No
Pearl-well 4	Yes	Yes	Yes	No
Well-XO1	Yes	Yes	Yes	Yes

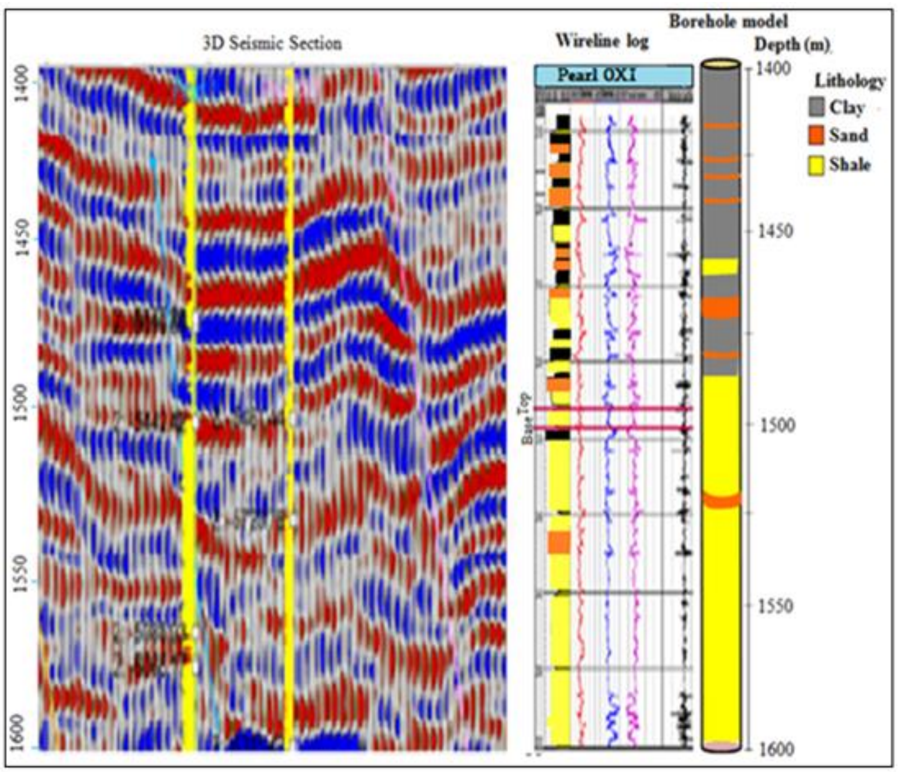

Figure 11: Showing Seismic-to-well tie and wells tying with Pearl-0X1 on Seismic Section. The resistivity log (red colour), gamma ray (blue colour), neutron log (purple colour) and check shot (black colour)

Faults Throw and Sealing Potential

The throw of the reservoir beds along the fault (F2 and F3) were analyzed. The area of interest binds the fault interpretation, which signifies that the faults are expected to show more displacement towards the end of the interpreted fault. Hence, the throw of the fault is the vertical component of the separation. The rollover anticlines are formed on the downthrown block of the

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fault F2 and F3 which depicts structural closure in the areas. Anticlinal are regarded as good hydrocarbon potential areas. In the eastern part of the growth fault, the up-thrown block is 1150 msec, the down-thrown block is 1200 msec and the throw difference is 50 msec. At the western part of the growth fault, the up-thrown block is 960 msec, the downthrown block is 1170 mec and the throw difference is 210 msec. This shows that the fault throw of major structure building fault (MSBF) in depocenter 5, increases from east to western part of the field (Figure 12). The hanging-wall is the major contributor to the accumulation of hydrocarbons since it is the moving part of the fault. The interpreted average throws of the major faults F2 and F3 are 50 msec and 210 msec. Therefore, based on the number of throws, faults F2 and F3 are sealing which is in agreement with the work of Weber and Daukoru (1975), signifying that in the Niger Delta, the soft and over-pressured Akata shale, in most cases rise up to fill the fault zones, thus enhancing their sealing capabilities. The major faults (F2 and F3) distance layers below 50 msec serve as migration pathways recharging shallower reservoirs within the rollover anticlines (at deeper depths). Hydrocarbon traps below 50msec exist as minor faults. A fault may act as a migration pathway or trap for hydrocarbon accumulation. In this research Figure 12 showed that below 50 msec, major faults act as a hydrocarbon migration pathway while above 50 msec, act as hydrocarbon traps due to their sealing capacity. Hence, fault throw does not control hydrocarbon migration pattern but control hydrocarbon accumulation.

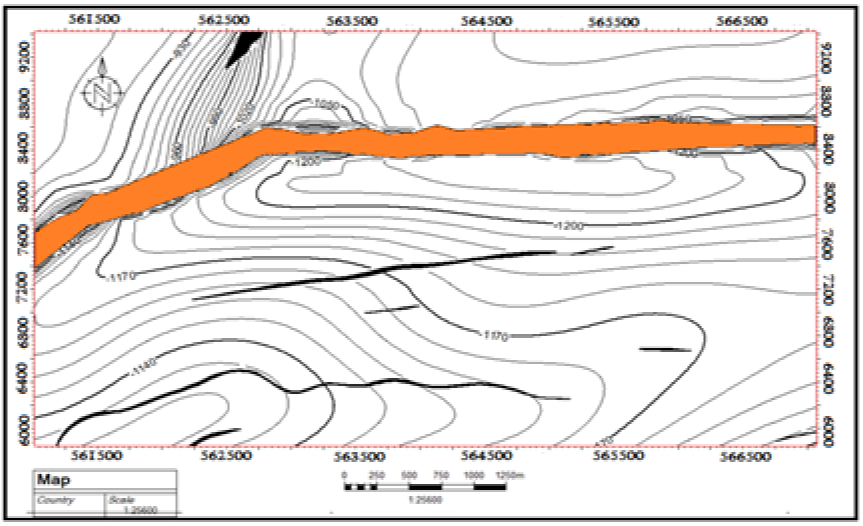

Figure 12: Showing interpreted structure map on major growth faults, its throw and sealing potential and interpreted fault attribute

Attribute Maps

The attribute maps were used for fault identification, visualized the faults trends, and generating time slices and the major sequence boundaries. The RMS amplitude attribute has an excellent resemblance to acoustic impedance contrasts and providing good reflection strength. It measures the highest amplitude values from the seismic dataset and displays hydrocarbon-prone areas Figure 13.

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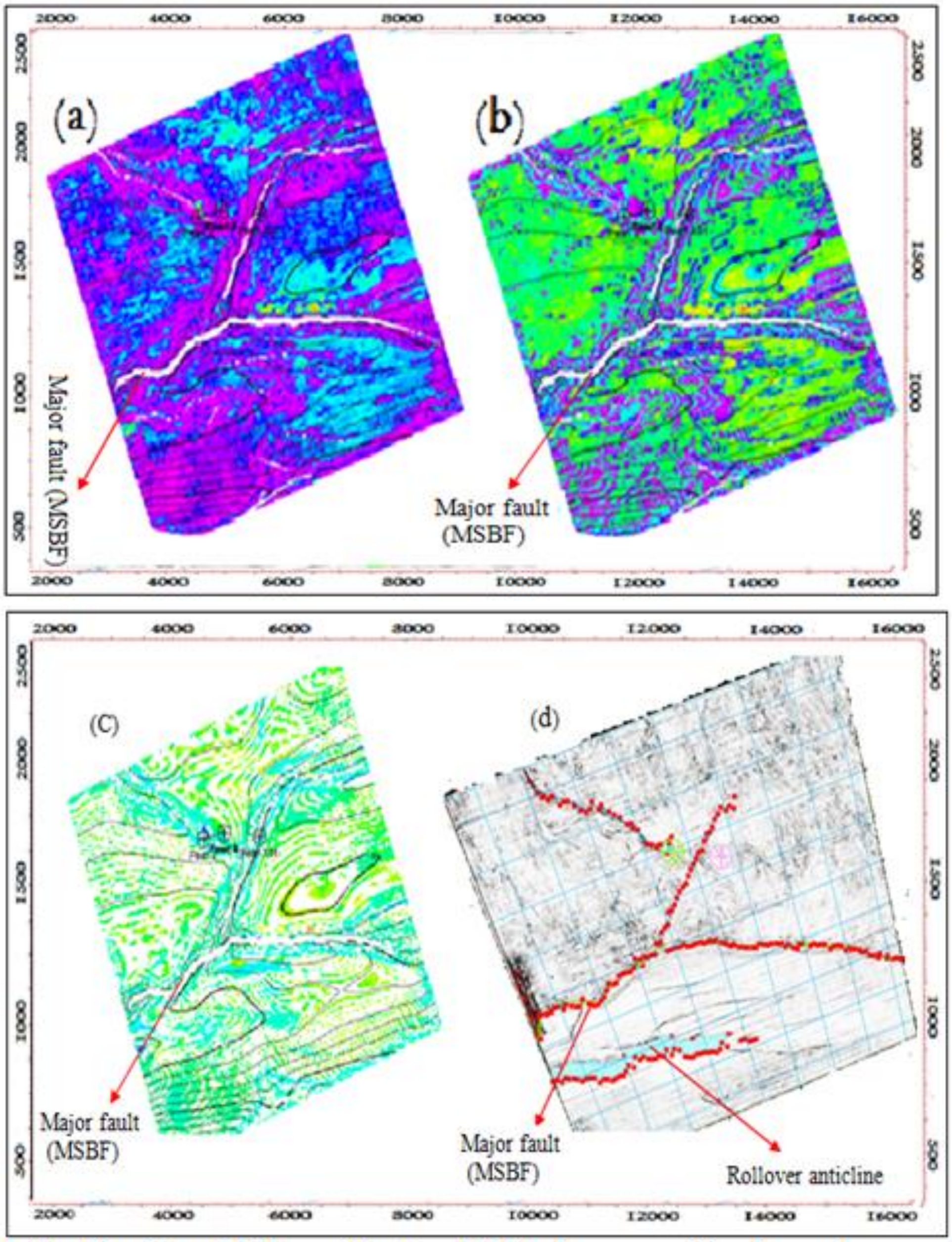

Figure 13 (a) Showing RMS amplitude, (b) Minimum amplitude, surface attribute (map view), (c) Maximum amplitude, and (d) 3D seismic at time slice-2344mse (attribute extracted in 3D volume

Trap Style Definition

Structural traps were identified from the closures on the time structural map generated. The contour patterns were used to identify fault assisted, fault dependent and anticline traps. Therefore, identified prospects were easily viewed. The 3-way structural trap assisted hanging wall closure depicted with a depth value of about 1210 msec, it closure is same as 4-way closure, provide in one side the trapping is provided by fault or pinch out. The 2-way fault closure has a depth value of about 955 msec, it closures trapping in two direction is provide either by faulting or pinch out. The 4-way fault closure has a rollover anticlinal structure with a depth value of about 1025 msec. A closure indicates that any hydrocarbons beneath a sealing stratum will be trapped in the feature. This mean hydrocarbon moved above the spill point got trapped (Figure 14). However, the study revealed that integrating information on structural maps and well log interpretation indicates that all of these wells have both growth faults and anticlinal structures that harboring potential accumulation of hydrocarbon in the PEARL Field.

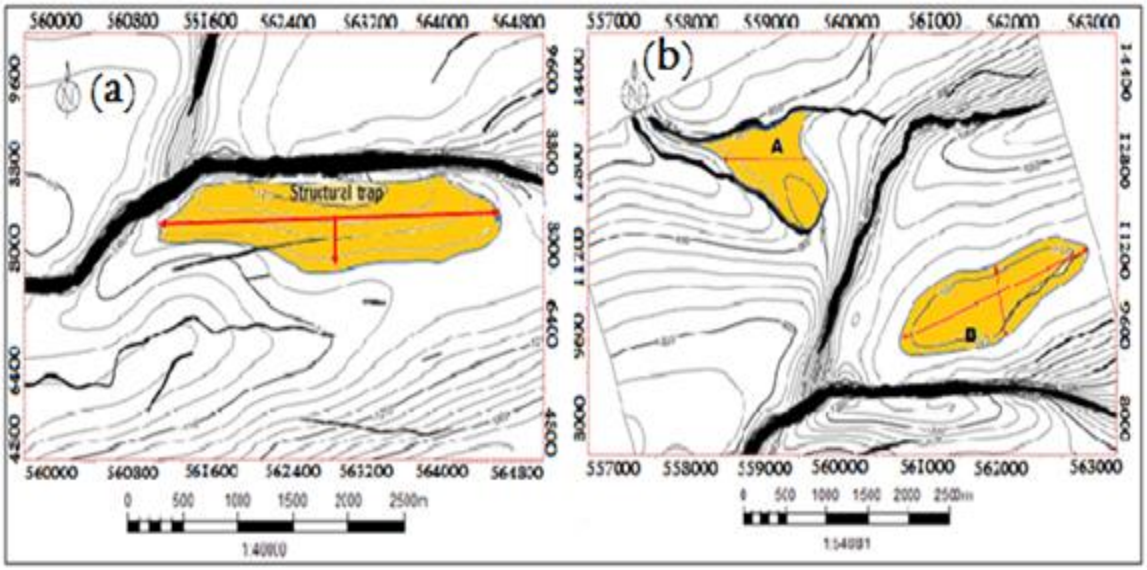

Figure 14: (a) Displayed structural trap on three-way assisted hanging wall closure and (b) displayed A as two-way fault closure and B as four-way closure (anticlinal trap)

Conclusion

Establishing of Pearl Field's structural framework has proved this research work's effectiveness. The interpretation of 3D seismic and well logs data revealed that the reservoir sands are in the paralic sequence with growth faults and associate rollover anticlines structure with a promising potential hydrocarbon accumulation. The reservoirs were mapped from the well using gamma-ray, lithology delineation and resistivity logs for fluid content identification. Twelve faults (F1, F2, F3, F4, F5, F6, F7, F8, F9, F10, F11 and F12) were delineated while horizon (H) was randomly picked across the seismic section. The generated time and depth structural maps show that the area is characterized by growth faults and rollover anticlinal structure which are potentially good for hydrocarbon accumulation. This study revealed that the field was controlled by the major growth faults and rollover anticlines formed by syn-sedimentary tectonic movements in the entire seismic survey. These shows that fault F2 and F3 in block E and F are the major structure building faults (MSBF) responsible for inducing a major structural trap at the western part of the survey. The rollover anticlinal feature at fault F2 and F3, down thrown block suggests the sand bodies, possible hydrocarbon migration and accumulation potential. Hence, this revealed that growth faults and rollover anticlines the highly faulted structural elements responsible for potential hydrocarbon accumulation.

Recommendations

1. Exploratory wells should be drilled within the mapped structurally high prospect areas.
2. During the hydrocarbon accumulation exploration, the structural framework would serve as a guide for the positioning of subsequent wells, thus, reducing the amount to be invested.
3. To predict hydrocarbon and enhance optimum recovery of hydrocarbon accumulation, integration of 3D seismic and well logs should be conducted.

Contributions to Knowledge

1. The presence of structural closures with significant trapping capacities in untested areas can form exploration targets of hydrocarbon.
2. Structural framework gives vital information to other geoscientists about the accumulation of hydrocarbon and thus reduces the level of uncertainty.

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