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Integrating Well Log and 2-D Seismic Data to Generate Inverted Acoustic Impedance for Stratigraphic Validation in Part of Upper Benue Trough (Gongola Basin), Nigeria.

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ABSTRACT

Integration of 2-D seismic and well log data of Gongola Basin was carried out to delineate the subsurface stratigraphy and define the basin structure beneath Gongola Basin in North-Eastern Nigeria. The 2D seismic interpretation revealed undulating basement topography, while structural analysis identified three predominant fault trends—NWSE, NESW, and NNW-SSE—forming horst and graben features in the region. Interpreting the gamma log from the well log suit, we identified and delineated subsurface stratigraphy in this area. The analysis uncovered a sequence of sandstone and shale, leading to the identification of four stratigraphic horizons—labelled as A, B, C, and D. These horizons are presumed to correspond to Gombe sandstone, Pindiga, Yolde, and Bima sandstone formations, respectively. The analysis also revealed the stacking patterns of individual sedimentary formations and their paleoenvironments of deposition asProgradational and aggradational.Moreover, the seismic inversion was carried out and the resulting model was calibrated with a well log from Kolmani-1. The time-depth relationship between the sonic log and seismic data was determined by tying a well with an intersecting seismic section and the inverted acoustic impedance was generated. The analysis of inverted acoustic impedance models also reveals four major stratigraphic units. The AI also reveals within these rock units the presence of some micro lithologicunits which may be a result of the intercalation of shale and sandstone. As in well interpretation, this analysis also reveals a sequence of alternating units of sandstone and shale which further validates the stratigraphy sequence beneath the area.

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1. Introduction

To bolster its hydrocarbon reserves, the Nigerian government made the strategic decision to expand its exploration efforts to include the inland frontier basins of Chad Bida, Sokoto, and Benue Trough. This determination was largely influenced by the successful discovery of substantial hydrocarbon deposits in neighbouring basins, including the Doba basin, Sudan's Muglad, and Eastern Niger, all of which are situated within the greater West African Rift System (WARS) (Abubakar, 2014; Abubakar et al., 2008; Akande et al., 2012; Nwachukwu, 1985; Obaje, Wehner, Scheeder, et al., 2004; Petters & Ekeozor, 1982). In the geological cycle, WARS is well known for the significant accumulation of hydrocarbons transmitted over its entire length (Abubakar, 2014; Abubakar et al., 2008; Akande et al., 2012; Benkhelil, 1982; Keller et al., 2006).

The Gongola Basin, located in the northeastern part of the Upper Benue trough, is an intriguing frontier basin that forms a part of the West and Central African Rift System (WCARS) (fig. 1). This basin has properties similar to those of other basins within CWRAS, such as its geological setting, structure, fauna assemblies, age, and organic matter quality. Several studies have been conducted in the area to understand the unique properties of the basin more thoroughly. Abubakar et al. (2006, 2008) conducted a study on the stratigraphy and basin evolution of the Gongola Basin. Akande et al. (2012) carried out a study to evaluate the hydrocarbon potential of the basin, while Asaah (2011) focused on its structural style and tectonic evolution. Bassey et al. (2017) investigated the sedimentary facies and depositional environment of the basin.

Exploration activities in the Gongola basin began in 1993, resulting in the drilling of three exploratory wells. Only Kolmani-River-1 yielded 33 billion standard cubic feet of gas with associated oil. The other two wells were dry. Work resumed when commercial quantities of oil were discovered in some WCARS basins, and the fourth well, Kolmai-2, was drilled by NNPC, which yields hydrocarbon of economic quantity. However, conducting more detailed work may further reveal the full potential of the basin for commercial exploration. As a result, many scholars in the relevant fields are conducting extensive studies on the viability and potential of the Gongola Basin for hydrocarbon exploration. Most of their research was aimed at obtaining more detailed information on the prospectivity of the basin. Among them are:(Abubakar et al., 2008; Akande et al., 2012; Bassey et al., 2017; Obaje, Wehner, Abubakar, et al., 2004; Oyebanjo et al., 2016; Sarki Yandoka et al., 2014)

The Acoustic impedance (AI) inversion has emerged as a popular technique for analyzing and understanding reservoir properties in recent years. This method involves the estimation of acoustic impedance from seismic data, which is then used to predict porosity, lithology, and other reservoir properties. Several studies have utilized this technique to explore reservoir characteristics in different parts of the world. For instance, (Erryansyah et al., 2020) applied acoustic impedance inversion to identify and characterize the target reservoir in Nias Waters, while Ejovi & John, 2019) integrated seismic and well log data using acoustic impedance for lithology and hydrocarbon evaluation of the "Ovi" Field in Niger Delta. (Ehirim, 2020)modeled porosity using acoustic impedance and well log data in EK Field, Niger Delta, which provided a geologically realistic porosity distribution and helped understand the reservoir image. (Purnama et al., 2018) utilized acoustic impedance inversion to identify oligo-miocene carbonate facies as a reservoir at the Kangean Offshore Area.

This work used AI to identify and characterize Kujung carbonate facies and predict porosity distribution. (Oyedele et al., 2020) applied seismic impedance inversion and attribute analysis to characterize the reservoir in an offshore depobelt of the Niger Delta, Nigeria. Alabi & Enikanselu (2019) integrated seismic acoustic impedance inversion and attributes for reservoir analysis to predict subsurface inter-well reservoir properties, fine-tune drilling locations within 'DJ' Field, Niger Delta, Nigeria, and describe optimum reservoir heterogeneity. (Mabrouk & Hassan, 2013) applied the inversion approach to estimate acoustic impedance from petrophysical data without density and sonic logs. .(Azuoko et al., 2021) applied rock property cross-plot analysis and post-stack acoustic impedance inversion for optimal reservoir characterization in the Alpha Field, onshore Niger Delta Basin. (Mahgoub et al., 2018) applied seismic acoustic impedance inversion to improve reservoir heterogeneity prediction and well placement. (Koesoemadinata et al., 2008) utilized acoustic impedance inversion for porosity and lithology prediction in the northern Gulf of Mexico, with the aim of transforming seismic reflection data into quantitative petrophysical properties. Finally, (Pharez et al., 1998 utilized layered acoustic impedance inversion to characterize the reservoir within the Ewan Field offshore Nigeria.

This research aims to conduct an integrated analysis of 2D seismic and well-log data to generate inverted acoustic impedance. The purpose of this analysis is to delineate and validate the stratigraphy below the study area. By combining these two types of data, we hope to gain a better understanding of the geology of the region and identify potential areas of interest for further exploration or development. This analysis will involve studying the seismic signals and well-log data to create a detailed and and highly precise model of the subsurface geology.

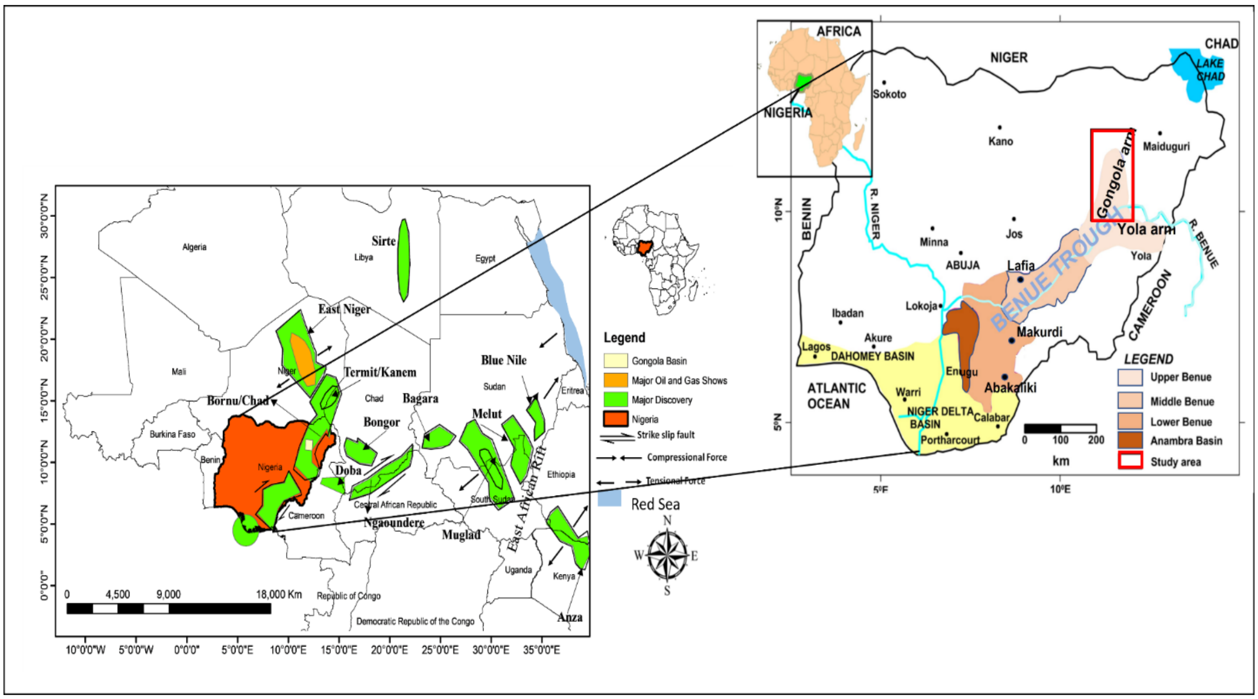

Figure 1: (a) Benue Trough and Gongola Basin within West and Central Africa Rift System (WCARS) (b) location of Benue Trough with Nigeria Source: Obaje (2004); Abubakar (2008) and Abdullahi.

2. Physiography and Geological Setting of Gongola Basin

The study area (Gongola Basin) is the north-south trending arm of the Upper Benue Trough in North-Central Nigeria (Figure 1). The area lies between longitude $10^{o}00'$ and $11^{o}30'E$ and latitude $09^{o}30'$ and $11^{o}30'N$. The area has a moderate gently undulating topography, (Figure 1). The terrain is characterized by gradual changes in elevation. the elevation in the map is depicted by ranges of colours. The orange to yellow indicate low land mostly the depobelts and have elevations ranging from 154 to 418m, whereas the olive green to blue colours indicates the highly elevated area which ranges from 419-1170m in height. River Gongola and its tributaries form the main drainage systems in the area (Figure 1). The River Maza is the main tributary and flows from the northwest to the southwest, joining the Gongola River.

The geology of the Gongola Basin (Figure 2), is composed of four geological formations: Pindiga, Gombe, Yolde, and Bima, with minor intrusions in certain locations. The Bima sandstone is the oldest formation, resting unconformably on the basement rock of Precambrian age, the transitional Cenomanian Yolde Formation, and the marine Turonian-Santonian Gongila, Pindiga, and Fika Formations. Above these formations are the continental Campanian-Maastrichtian Gombe Sandstone. The youngest sedimentary formation in Gongola Basin is the Kerri-Kerri Tertiary-recent, marking the end of sedimentation in the Upper Benue Trough. In the Yola Arm, the Turonian-Santonian sequence is replaced by the equally marine Dukul, Jessu, Sekuliye Formations, Numanha Shale, and the Lamja Sandstone(Pearson & Obaje, 1999; P. Zaborski et al., 1997). The Basement rocks underlying the study area, particularly those that appear as exposures, are categorized as Older Granite, which comprises granites, granodiorites, and mylonites(Osinowo & Abdulmumin, 2019). The geology and stratigraphy of the Gongola Arm of the Upper Benue Trough in northeastern Nigeria have been well-documented by various authors, including (Abubakar et al., 2006, 2008; Adegoke et al., 1986; Carter et al., 1963; M. Guiraud, 1990; M. Guiraud et al., 1989; R. Guiraud & Maurin, 1992; Obaje, 2009; Obaje, Wehner, Scheeder, et al., 2004; Ojo & Pinna, 1982; Tukur et al., 2015; P. M. Zaborski, 1998)

The Upper Benue Trough spans approximately 300 km in length and 150 km in width. The basinis underlain by a Precambrian crystalline basement reactivated during the Pan-African thermotectonic phase (M. Guiraud, 1993). Structurally is divided into the east-west trending Yola Basin (or "Arm") and the north-south trending Gongola Basin (Fig. 2.3), while Benkhelil, (1989); Dike, (2002) and Guiraud, 1993) recognized a third basin, the northeast-southwest trending Lau Basin or main arm. The two branches of the Upper Benue Trough are separated by an area structurally dominated by four major strike-slip faults; the Gombe, Bima-Teli, Kaltungo, and Burashika faults (Abubakar, 2014; Tukur et al., 2015). This median zone was regarded as the partially exposed basement high characterizing the axis of the Benue Trough by Benkhelil, (1989) and Maurin et al., (1986) and it was referred to as the 'Zambuk ridge' by (Carter et al., 1963), while (Guiraud, 1993) called it the "Wuyo-Kaltungo high".

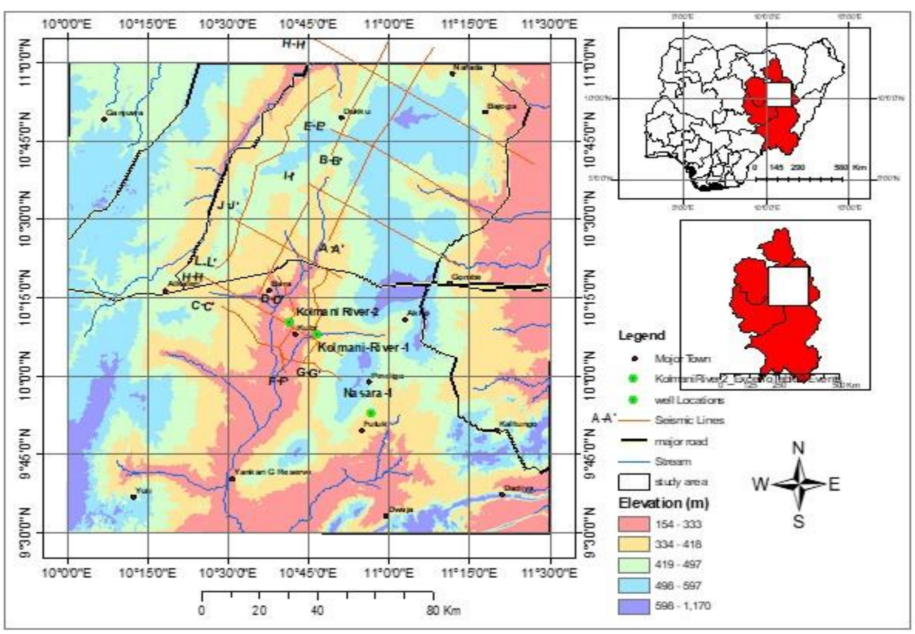

Figure 2: Location of the Study Area Showing Drainage Pattern, Locations of the Seismic Lines and Well

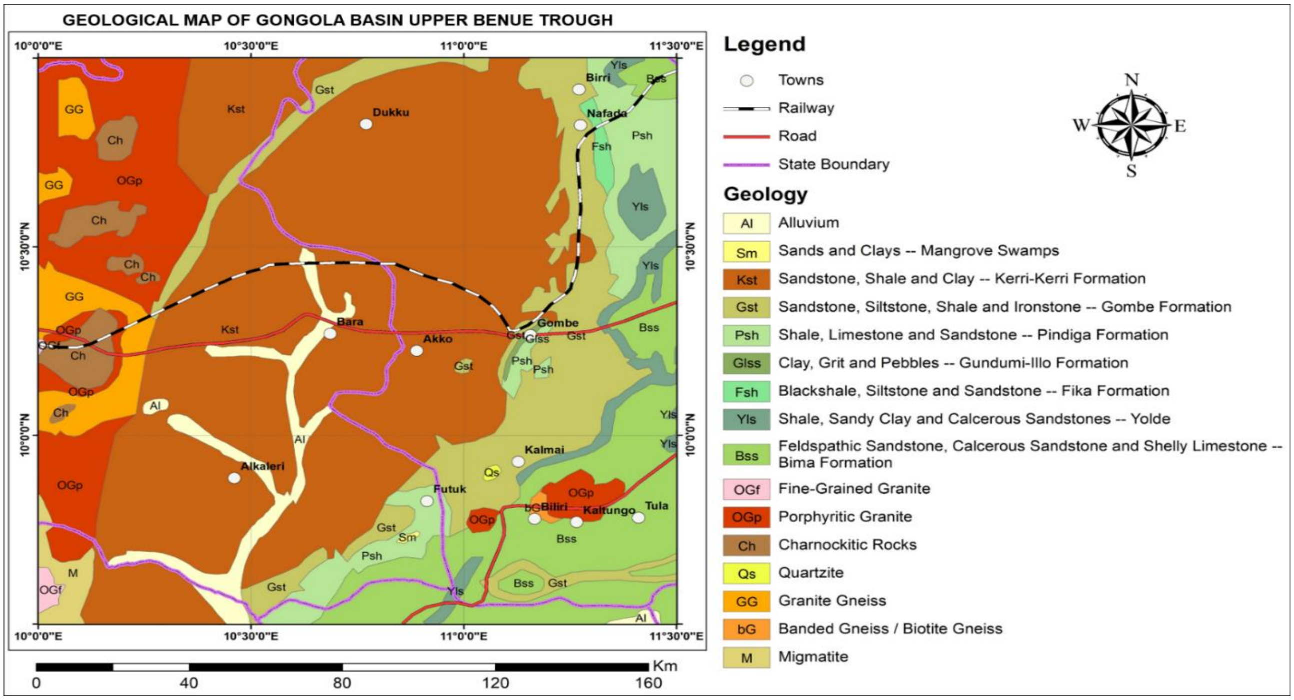

Figure 2: A Geological map of Nigeria of Gongola Basin Gongola Basin

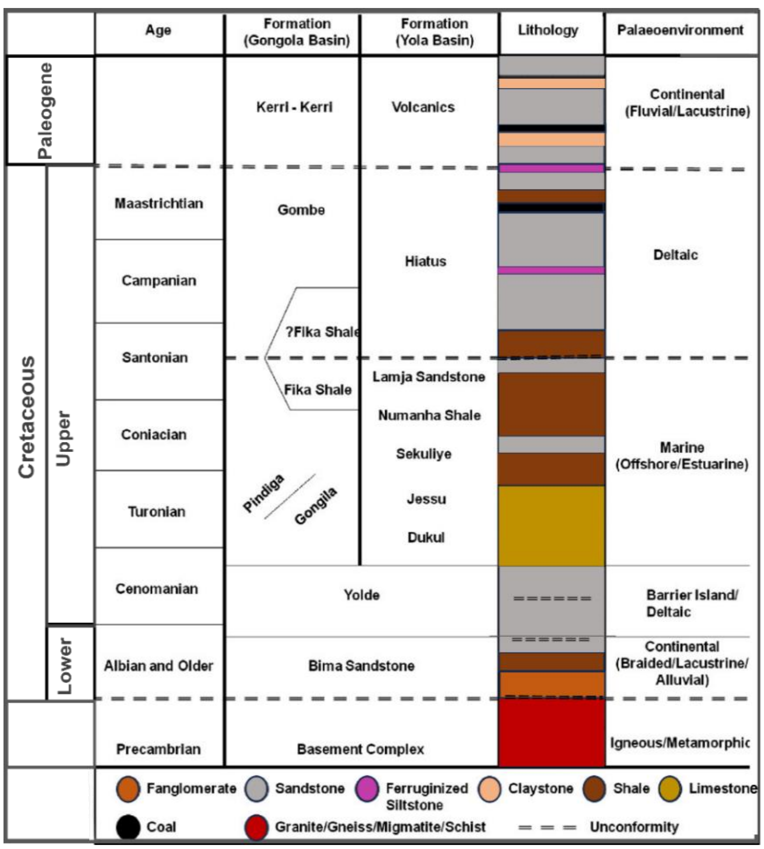

*Figure 4: Stratigraphic succession in Upper Benue Trough*Source: After Abubakar et al., (2006); Obaje, Wehner, Abubakar, et al., (2004)

3. Research data

The seismic data used in this study was obtained exclusively from the Nigerian National Petroleum Corporation (NNPC). The data is composed of post-stack time migrated 2D seismic reflection survey data. Seismic data is important for exploring the subsurface geology of an area. It was used in this study to provide additional information on the subsurface structure and to help identify areas with potential for oil and gas exploration.

It is important to note that all the data used in this study was obtained from reliable sources and is of the highest quality. The data was carefully processed and analyzed to ensure accuracy and reliability of the results.

4. Methodology

The workflow employed in this study is summarized in Figure 5. The work began with seismic Interpretation followed by well-log interpretation and correlation in order to build an initial stratigraphic framework for the basin. The well logs used for correlation included gamma-ray, resistivity, density, and sonic logs. The logs were used to define the stratigraphic framework in the area. Sonic log velocity data were extracted from the Kolmani-1 well, which is directly located on the S-N oriented G-Gˈseismic Line. The seismic data were processed to be zero-phase according to the SEG-Y file headers. Time-migrated versions of the seismic data were used for this study.

The log-based stratigraphy was transferred to the seismic data using synthetic seismograms. This was followed by a detailed stratigraphic interpretation of the seismic data that merged the well-based stratigraphy and seismic reflection patterns. Following this conventional seismic stratigraphic interpretation, we extended our stratigraphic interpretations using acoustic impedance methods for predicting rock properties.

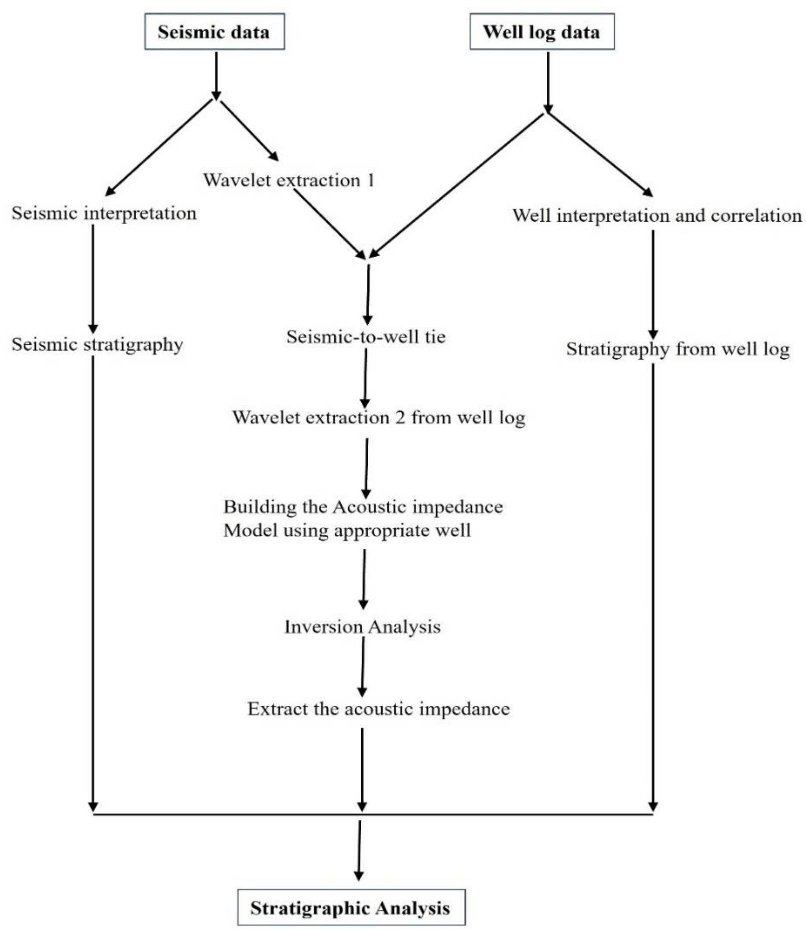

Figure 2: Research Workflow Chart

5. Theoretical background

The acoustic impedance Z is an essential property of a rock layer, and is utilized to determine the Earth's reflection response. It is a contrast across the different rocks interface, which determines the relative quantities of energy transmitted and reflected. It is mathematically defined as the product of its density (ρ) and its wave velocity(v); and is expressed as,

$$Z = \rho v \quad 1$$

The amount of energy transmitted through the interface is inversely proportional to the acoustic impedance. It is difficult to relate acoustic impedance to a tangible rock property, but, in general, the harder the rock, the higher is its acoustic impedance. Intuitively, the smaller the contrast in acoustic impedance across rock interfaces, the greater the proportion of energy transmitted through the interface. All the energy is transmitted if the rock material is the same on both sides of the interface, and the more energy is reflected, the greater the contrast.

Within the Earth, reflections occur at the interfaces between layers, and the reflection amplitudes depend mostly on the difference in acoustic impedance from layer to layer. This Reflected amplitude is the difference between the two impedances of each layer divided by their sum. The ratio of the reflected amplitude to the incidence amplitude is called the reflection coefficient and is given by the difference in acoustic impedance divided by their sum. This is expressed as reflection coefficient, R, given by

$$R = \frac{A_1}{A_o} = \frac{Z_2 - Z_1}{Z_2 + Z_1} \quad 2$$

where Z_1 is the acoustic impedance on the incident ray side of the boundary and Z_2 is the acoustic impedance on the side of the transmitted ray. Reflectivity can be either positive or negative.

In its simplest form, the reflection coefficient is related to a change in acoustic impedance, thus Equation 63, the reflection coefficient can still be expressed as

$$R = \frac{\rho_2 v_2 - \rho_1 v_1}{\rho_2 v_2 + \rho_1 v_1} \quad 3$$

The sum in the denominator of the reflection coefficient Equation does not have much effect. Instead, the difference in the numerator dominates the reflection coefficient.

Analysis of Seismic and Well-Log to Generate Acoustic Impedance

The workflow employed in this study is summarized in Figure 15. The work began with seismic Interpretation followed by well log interpretation and correlation in order to build an initial stratigraphic framework for the basin. The well logs used for correlation included gamma-ray, resistivity, density, and sonic logs. The logs were used to define the stratigraphic framework in the area. Sonic log velocity data were extracted from Kolmani-1 well, which is directly located on the S-N oriented G-Gˈseismic Line was. The seismic data were processed to be zero-phase according to the SEG-Y file headers. Time-migrated versions of the seismic data were used for this study.

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Seismic interpretation

The 2D seismic data were displayed in normal SEG-Y polarity with a downward increase in reflection time for a zero-phase wavelet reflection wiggle and a positive reflection coefficient having a central wavelength peak. In addition, the processed seismic sections possessed a high signal-to-noise ratio (S/N) with smooth and continuous phase reflections, allowing for simple auto-tracking of the strong seismic reflections. However, where seismic data are incoherent due to high noise, reliable manual horizon mapping is applied in tracing the horizons.

Seven seismic lines B-Bˈ, D-Dˈ, E-Eˈ, G-Gˈ, H-Hˈ, K-Kˈ, and L-Lˈ were selected out of many available seismic lines in this study and are represented respectively in Figures 31 a, b, c, d, e, f and g). These seven seismic lines were carefully selected across the area to have a detailed subsurface image of the basin. The seismic sections were interpreted using time-migrated profiles. Due to the lack of rock outcrops and core samples for this investigation, biostratigraphic and lithostratigraphic data extracted from well reports were utilised for age control and the geological interpretation of seismic occurrences to identify and delineate seismic horizons and subsequently, the stratigraphic units in the area.

6. Acoustic Impedance Inversion

(a) Well-to-Seismic Tie

During seismic to well tie, well data (logs) and seismic data were correlated to well data to know to establish a tie between changes in rock characteristics in a borehole and seismic reflection data and also to relate peaks and troughs on the seismic section as done by (González et al., 2021). The synthetic seismogram here was generated to provide a fundamental link between well data and seismic data. The process involves creating a reflection series in the time domain constructed to identify seismic reflections. Also, velocity or check-shot survey data are required for time-depth tying of the seismic to the well. In this study, however, a check shot was unavailable; the correlation method provided by (Simm & Bacon, 2012), which involved the use of time-depth components present in the sonic log, was adopted. In the process, the seismic section was first converted from time to depth domain using the velocity data extracted from Kolmani-1 sonic log data. Then wavelet which is an essential element in the seismic-to-well tying process was extracted—the more suitable the wavelet, the better the matching between synthetic and trace seismic. The wavelet in this process was generated using phase rotation of zero-phase synthetic and convolved with the reflection series. The wavelet that matches the energy spectrum of the data window and phase rotates, and time then shifts it to optimise the match. Shifting and stretching are done to get a good correlation to optimise the match. A common reason for stretching and squeezing synthetics is to generate background models for seismic inversions so that the inversion results fit the well. However, stretching was done carefully to avoid excesses because the stretching process can change the log data.

Acoustic impedance inversion was computed on the synthetic traces drived during well-to-seismic tie. The flowchart of the process is shown in Figure 16. From the acoustic impedance inversion, three sections were developed which relates acoustic impedance with gamma-ray porosity and P-wave velocity.

7. Result Interpretation and Discussion

8. Seismic stratigraphy

According to the results obtained from the seismic survey conducted in the Gongola Basin, it has been observed that the sedimentary rock record is encompassed by a thick series of reflections. In addition to this, several high amplitude patterns have been discovered, which exist parallel to sub-parallel or dipping reflections, overlaying discontinuous and low reflection patterns. interpretations of two seismic lines G-Gˈ, and L-Lˈ Figure 6 and 7 respectively suggest that the basin contains four reflectors, A, B, C, and D, respectively corresponding to the base of Gombe sandstone, Pindiga formation, Yolde formation, and Bima.

It has been noted that the depth of the last seismic reflectors identified varies across different seismic sections, indicating variations in the basement surface. Specifically, in sections F G-G’ (S-N), the reflectors are shallower towards the north and deeper towards the south. Section L-L’ reveals that the reflector is shallower in the northwest and deeper in the southeast. The number of reflectors revealed by each seismic line ad their corresponding lithology is summarized in Table 2

Table 1: Summary of Seismic reflectors and the stratigraphy delineated

Profile	Direction	Location	Profile Length (m)	No. of Reflection surface	Possible rock units
G-Gˈ	(S-N)	Maimadi to Hashidu	41,159	4	GM, PD, YD and BM
LLˈ	(NW-SE)	Pali to Akko	60,188	4	GM, PD, YD and BM

Where, Gombe sandstone (GM), Pindiga formation (PD), Yolde formation (YD) and Bima sandstone (BM)

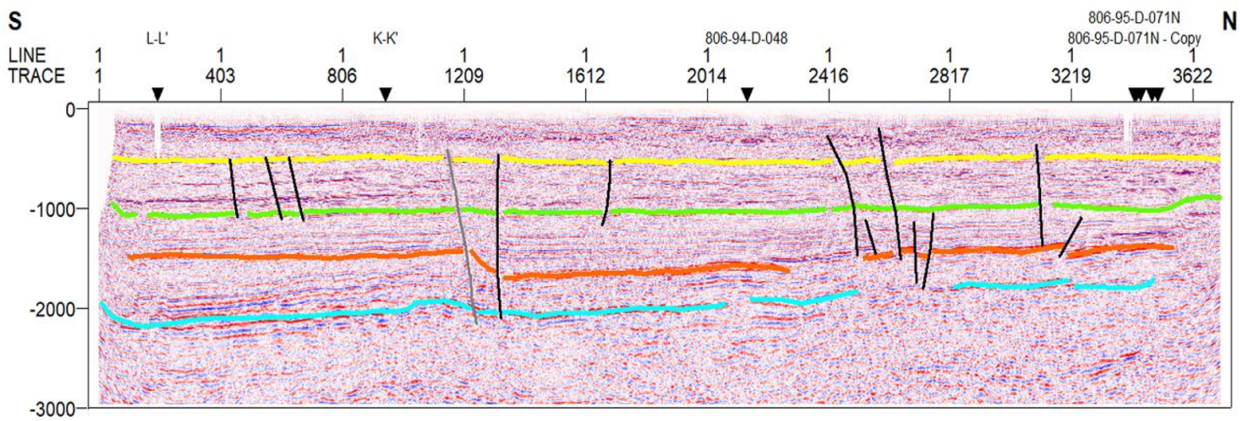

Figure 6: The seismic sections along G-Gˈseismic lines from Maimadi to Hashidu

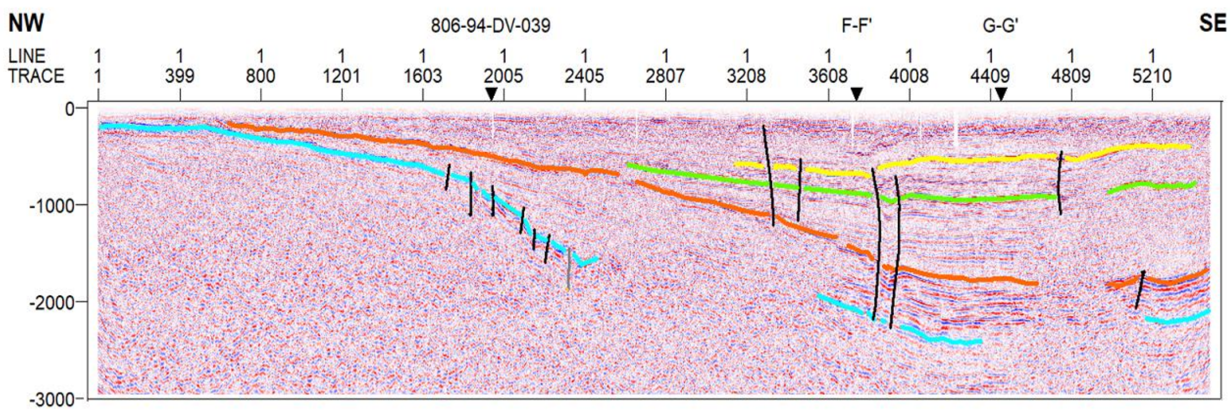

Figure 7: The seismic sections along LLˈseismic lines from Pali to Akko

9. Stratigraphic identification from well correlation

In most stratigraphic and petroleum geological applications, gamma-ray log is used to differentiate shales from "clean" formations and estimate the shale proportions in shaly reservoir units. It helps in sequence stratigraphic analysis and identifies boundary intervals that correspond to different types of well logs. This facilitates better interpretation of the stratigraphic features and a more detailed understanding of the geological formations. The abrupt change in the GR log response is viewed as being related to severe lithological breaks linked to unconformities and sequence boundaries. By identifying the boundary intervals that correspond to different types of well logs for each individual well, it becomes possible to delineate the well log facies into distinct genetic groups with lateral relationships. This enables a more detailed understanding of the geological structure and facilitates better interpretation of the stratigraphic features.

In this study, gamma-ray logs from Kolmani-1 and Nasara-1 located within the Gongola basin were correlated to delineate major lithostratigraphic units (Figure 34). The gamma-ray logs from these two wells do not have a perfect match or clearly defined stratigraphic boundaries, which would have made horizon delineation much simpler. In addition, most log lengths are characterized by jagged curves, making well correlation challenging. However, horizon identification is accomplished through a combined study of the lithology from the well report and the gamma log. After their identification and delineation, these horizons have been named Top, A, B, C, and D, respectively (Figure. 9).

The top horizon is the uppermost layer delineated from the wells. The horizon is only found in Kolmani River-1 but missing in Nasara-1 due to erosion. The top horizon is characterised by a less spiky curve and less gamma rays revealed by the horizon, indicating that the stratigraphy unit is dominated by sandstone with no or little shale. The A next horizon beneath the uppermost horizon is A. The horizon is characterized by uneven, blocky, with low gamma-ray log values which gradual increase upward and decrease after certain point, indicatve of shale increase with sandstone bed at the top. B is the horizon underlying horizon A. The stratigraphic unit displays irregular blocky-shaped log curves with highly and closely spaced spikes associated with alternating sharp increases and decreases in GR log values, forming an overall saw-toothlike shape typical of alternating sand and shale sequence. The stratigraphic unit C also exhibits irregular saw-tooth-shaped, closely spaced, very spiky log curves, which increase and decrease alternatively over the unit, typical of a predominantly sandstone unit intercalated with shale.Using the geology of the area from well reports as a guide, these horizons are presumedto be the equivalent of Gombe sandstone, Pindiga, Yolde and Bima formations.

Glover (2001; Hancock (1997); Krassay (1998); Omoboriowo *et al*. (2012); SEPM (2015) classified three commonly recognized gamma ray log shapes: funnel, bell, and cylindrical. These shapes suggest a discrete sedimentary cycle (Figure. 8). Funnel-shaped gamma ray log with gamma-ray counts decreasing upward, indicating progressively coarser or sandy sedimentary sequence denote progradational stacking pattern. Bell-shaped gamma ray log with gamma ray count increasing upward indicating finer or shaly sedimentary sequences denote retrogradational stacking pattern. These three shapes can be subdivided into smooth or Block-shaped (relatively homogeneous) or serrate (with interbedded thin shales) (Hancock, 1997). These characteristic log shapes are more apparent when the GR log is paired with resistivity log where the patterns are mirrored.Figure 33, as applied by Kim et al. (2012), Onyekuru et al. (2019), Radwan (2021), and SEPM (2015), defines the depositional environment. Table 2 summarizes the details of delineated horizons.

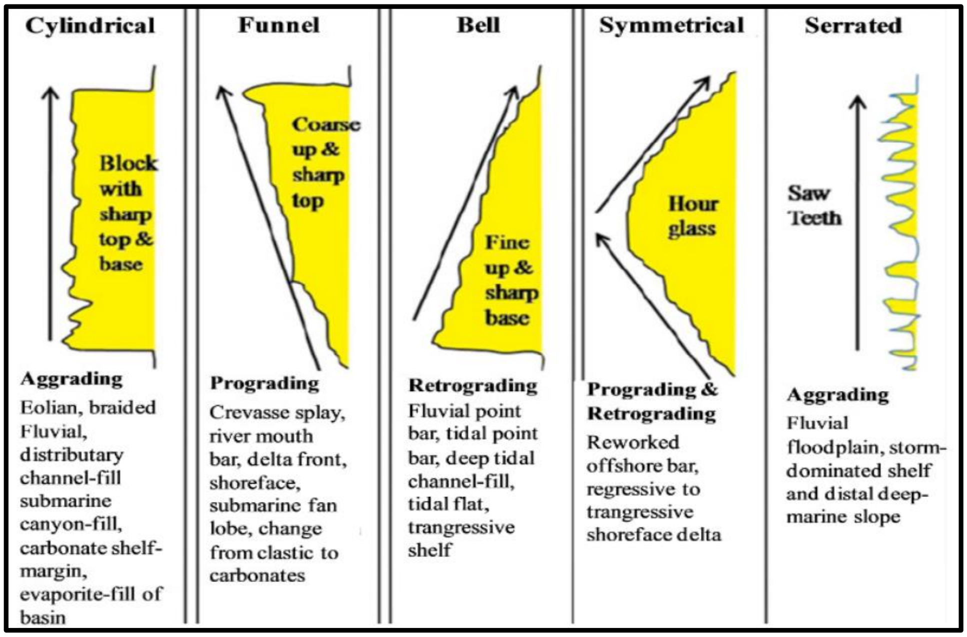

Figure 8: Response of Gamma-ray Log Signal to Variation in Grain SizeSource: Kim et al. (2012); Onyekuru et al. (2019); Radwan (2021); SEPM, (2015)

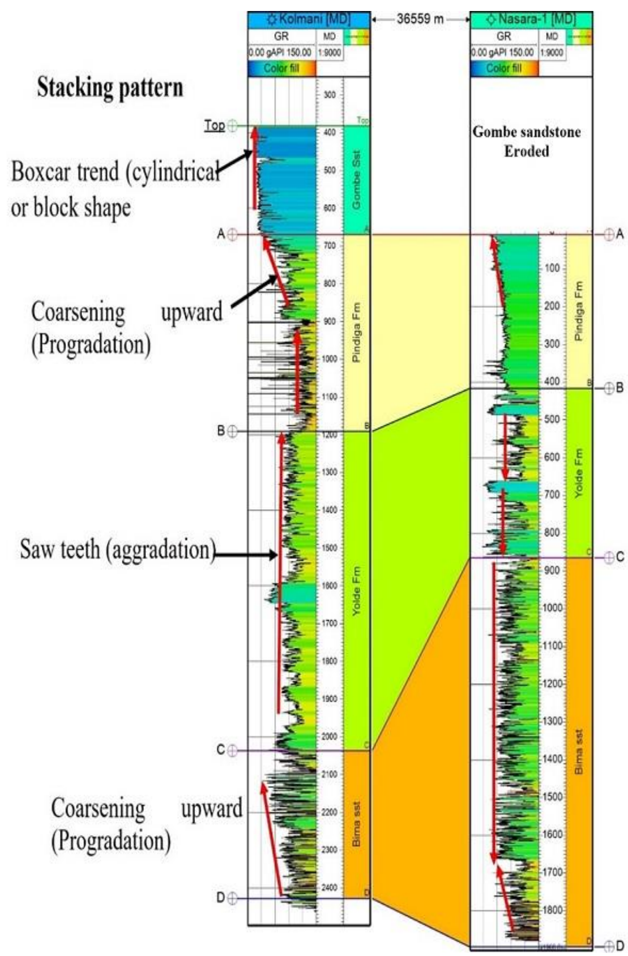

Figure 9: Well Correlation showing Interpreted Stratigraphy Correlated to a Gamma-Ray Log

Table 2: Inferred lithology, and Geologic Formation with their Corresponding depth Delineated from the Correlation of Gamma-Ray Log for Kolmani River-1 and Nasara-1 wells

Kolmani River-1 well				
Formation	**Formation top (m)**	**Formation depth (m)**	**Formation thickness (m)**	**Inferred Lithology**
Gombe Sandstone	390	670	280	sandstone with little or no shale
PindigavFormation	670	1190	520	shale with interbedded sandstone
Yolde Formation	1190	2030	840	sand and shale sequence
Bima Sandstone	2030	2430	400	Sandstone unit intercalated with shale
Nasara-1 well				
Formation	**Formation top (m)**	**Formation depth (m)**	**Formation thickness (m)**	**Inferred Lithology**
Gombe Sandstone is missing here due to erosion	-	-	-	sandstone with little or no shale
PindigaFormation	10	410	400	shale with interbedded sandstone
Yolde Formation	410	870	460	sand and shale sequence
Bima Sandstone	870	1900	1030	Sandstone unit intercalated with shale

10. Stratigraphic Validation from Well-To-Seismic Tie and Inverted Acoustic Impedance

Lithology and stratigraphic interpretation from acoustic impedance inversion involves analyzing the acoustic impedance data and making inferences about the rock types present in a subsurface formation. By examining the variations in acoustic impedance values, different lithologies can be identified and correlated with specific rock formations. This approach utilizes the relationship between acoustic impedance and the physical properties of the rocks, such as porosity, mineral composition, and fluid content. Through geological knowledge and interpretation techniques, the inverted acoustic impedance data can provide valuable insights into the lithology and geological characteristics of the subsurface.

In this study, we carry out the analysis of acoustic impedance to further validate the stratigraphy delineated from seismic section and well log earlier discussed. Seismic inversion of rock units beneath Gongola Basin has revealed contrasts in acoustic impedance which may be caused by changes in lithology and/or porosity. Figure 10 and 11 show the relationship between inverted acoustic impedance and gamma ray and porosity log respectively. The analysis of acoustic impedance make the identification horizon easier and it further reveal more clearly micro stratigraphic units within the delineated horizons. Similar to correlation, acoustic impedance also reveal four major stratigraphic layers with some untramocro units. More so, pinch- out on the northern part of the section and it serve as a stratigraphic trap which may impede further migration of the fluid. The technique revealed that the porosity and P-wave velocity values range from 6000-7500, and 20 – 35 % respectively. The value range of the porosity is enough to hold oil and gas while and may easily flow into the reservoir The synthetic seismogram presented in Figure 35 was also utilized in identifying and characterizing the stratigraphy of the area under study. Through the use of this method, four distinct stratigraphic units, including the surface layer, were successfully delineated. The highly detailed information obtained from this approach allowed for a more comprehensive understanding of the geological history.

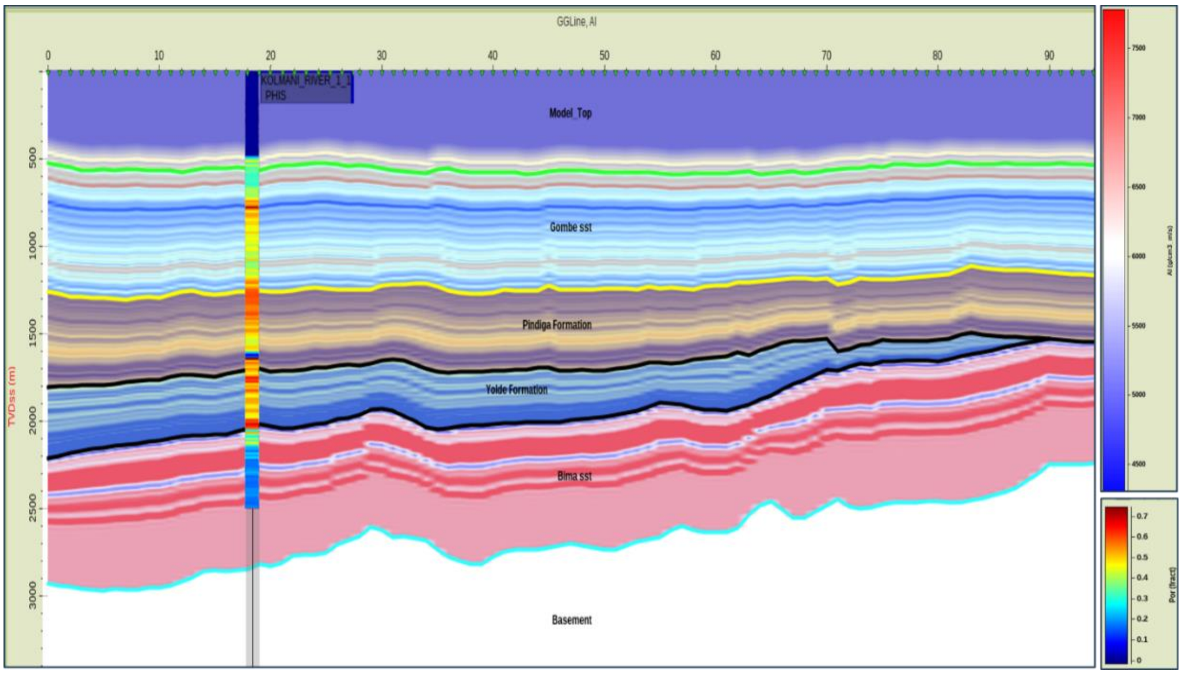

Figure 10: Inverted Acoustic Impedance Section and Lithology from Gamm-Ray Log

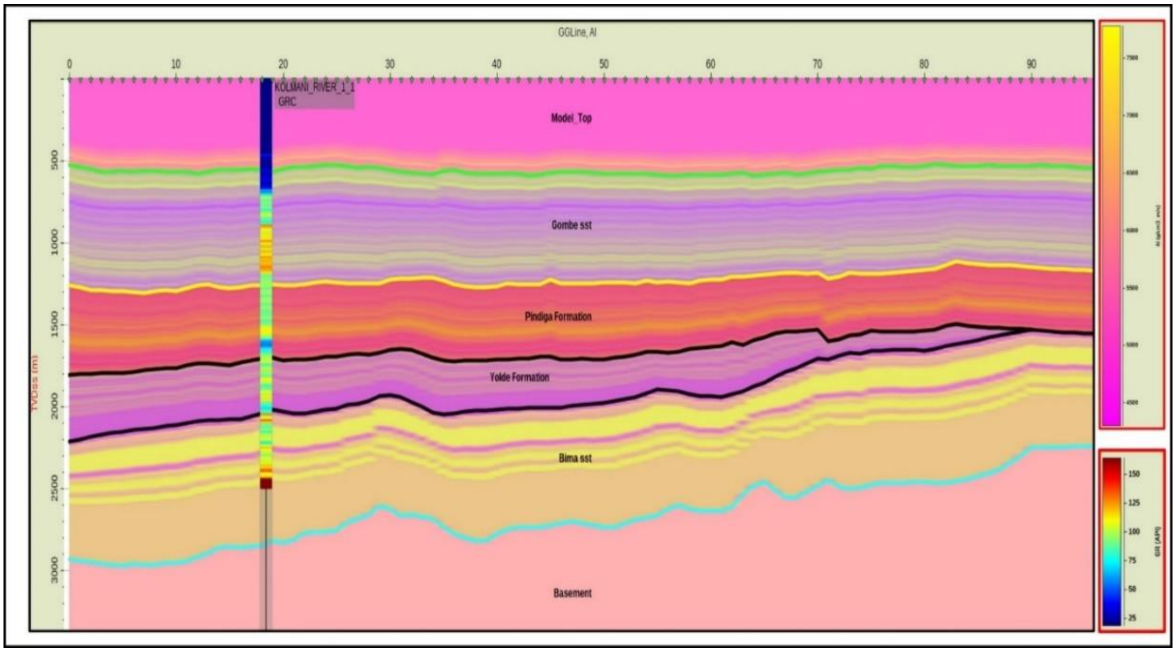

Figure 11: Inverted Acoustic Impedance Section and Porosity Log

11. Summary and Conclusion

The present study, involves. Integration of 2-D seismic post stacked and two well log data of Gongola Basin was carried out to delineate the subsurface stratigraphy and define the basin structure beneath Gongola Basin in North-Eastern Nigeria.

The study provided alternative method for stratigraphic studies in the Gongola Basin rather than the traditional field methods applied in most of the research around Gongola basin. Most of the previous studies that previous studies are base on stratigraphic facies interpretation using cores and outcrop data. However, subsurface facies characterisation from well log data allows for enhanced correlation of inferred strata from continuous data. This study has demonstrated the accuracy of data correlation and supports the objective of multi-source data integration. The following is specifically concluded:

- The analysis of Well log and seismic data, which involves seismic interpretation, well log interpretation and correlation seismic-to-well tie, depicts that the subsurface stratigraphy consists of sand-shale interbedding.
- Four stratigraphic horizons A, B, C, and D, were delineated. The horizons are presumed to be equivalent of the Gombe sandstone, Pindiga, Yolde and Bima sandstone formations, respectively.
- The stacking patterns of individual sedimentary formations were deduced from the combined well log analysis.
  - Gombe sandstone here is reveals a Boxcar trend (cylindrical or block shape): with low gamma and sharp boundaries and no internal change which indicate that the trend is predominant in fluvial channel sands,
  - Bima and Pindiga Formations were characterised by aggradational stacking pattern
  - Yolde Formation is characterised by aggradation stacking pattern which is an indicative of shale or silts.
- Structurally, the analysis of the seismic section indicates two main structural trends consisting of NNW-SSE trending lineaments and NE-SW trending lineaments observed in most of the NE-SW oriented seismic lines.
- The depositional pattern in the area was controlled by the basement tectonic features

forming horst and graben and associated faults, which originated from the Cretaceous rifting and basin evolution.

12. References

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