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Seismic Characterization of Tertiary-Cretaceous Formations of Lake Sub-Basin, Borno, Nigeria

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ABSTRACT

The Borno Basin is a frontier basin within the Mesozoic–Tertiary African rift system that originated in the Early Cretaceous and is situated in northeastern Nigeria, part of the Mega-Chad Basin. This study integrates 3D seismic interpretation with limited well control to delineate the subsurface structural framework of Block 1 within the Lake Sub-Basin. Interpreted seismic horizons range from 250 ms to 3000 ms, indicating progressive eastward thinning of sedimentary units that reflect regional tectonostratigraphic variations. Structural analysis identifies simple anticlines within the Cretaceous succession as the dominant trapping structures, whereas fault systems exhibit significant deformation and poor lateral continuity. Most faults terminate at the angular unconformity separating Cretaceous and Tertiary strata, highlighting a major tectonic discontinuity. Two principal fault types were recognized: deep-seated synthetic faults propagating upward from the basement and antithetic relief faults confined to the sedimentary section. Fault orientation statistics show NW-SE trends as the most prevalent (45%), followed by N–S (21%), NE–SW (27%) and E-W (7%) orientations, thereby refining earlier interpretations that emphasized NE-SW dominance. The results suggest that the Borno Basin is characterized by gentle folding, multi-directional faulting, and variable sediment thickness. These structural insights enhance understanding of the basin's tectonostratigraphic evolution and improve constraints on hydrocarbon prospectivity in this underexplored frontier region.

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1.0 Introduction

Boosting daily oil and gas production and current reserves requires sustained exploration, especially in underexplored frontier basins such as Chad, Anambra, Dahomey, Sokoto, Bida/Nupe, Gongola, Yola, and the Benue Trough [1, 2]. In Nigeria, hydrocarbon exploration has primarily focused on the major hydrocarbon producer, the Niger Delta, with limited attention to the frontier basins. Discoveries in the Kolmani River II appraisal well in Gongola's upper Benue Trough are significant for Nigeria's energy and economy, highlighting the potential of frontier basins to boost energy security and growth [1, 3, 4]. The 2021 Petroleum Industry Act (PIA) reinforces this, mandating that NNPC allocate 30% of its net revenue to frontier basin exploration.

The Lake area is one of three sub-basins in the Borno Basin, located in the southwest of the Termit-Agadem basins of Chad and Niger. The Borno Basin is also known as the Nigeria-Chad Basin, which is an intracratonic rift basin covering about 2,400 square kilometers. It spans Cameroon, Chad, Niger, and northeastern Nigeria, with about 10% in Nigeria. The basin has attracted efforts from government agencies and universities since the 1970s, sparked by a large negative Bouguer anomaly identified in studies. Hydrocarbon discoveries in surrounding basins such as Bongor, Doseo, Doba, and Termit in Chad, and Agadem and Kafra in Niger, have renewed interest in the Borno Basin's potential, emphasizing the region's hydrocarbon prospects and encouraging further exploration [5].

Bedrock exposures in the basin are uncommon due to the thick Quaternary sediments that cover them, especially in the north, near Lake Chad and the Chad Republic [6]. Some outcrops are found in the northern Upper Benue Trough [7, 8]. The stratigraphic framework mainly depends on limited rock exposures, core samples, and well cuttings from shallow wells and from the Nigerian National Petroleum Corporation [9-12]. In 2015, Isyaku and his research teams analyzed multi-well log data from twenty-three wells in the basin's northeastern part [6]. Organic geochemistry of shale samples from the Gongila and Fika Formations in some wells indicates low thermal maturity and poor to fair source rock potential [13-18]. The source rock potential of the Bima Formation is limited, with low organic content in many wells in the Maiduguri and Lake Chad regions, further restricting its effectiveness.

Given these geological and data constraints, seismic interpretation offers a critical tool for resolving subsurface architecture and improving hydrocarbon evaluation in the basin [19]. The integration of 3D seismic data with well-log control enables precise delineation of structural geometries, mapping of fault systems, identification of stratigraphic features, and characterization of sedimentary packages across the Tertiary-Cretaceous interval [19-21]. Seismic interpretation is a fundamental tool for understanding subsurface architecture, particularly in frontier basins where outcrop and well control are limited [20, 21]. By analyzing variations in seismic reflectivity, interpreters can delineate key stratigraphic horizons, identify structural traps, map fault networks, and reconstruct depositional frameworks across large areas with high spatial continuity. The integration of 3D seismic data with well-log information significantly enhances interpretation accuracy, allowing the calibration of seismic reflections to true lithological and stratigraphic units [20]. This synergy enables the detection of subtle structural features such as growth faults, unconformities, fault terminations, and gentle folding that may not be directly observable in well data alone [21].

In rift-influenced basins like the Borno Basin, seismic interpretation is particularly important for unraveling tectonostratigraphic evolution, assessing sediment distribution patterns, and evaluating potential hydrocarbon traps within the Tertiary-Cretaceous succession [21]. This study employs an integrated approach by merging 3D seismic data with well-log information to visualize subsurface structures, define the structural configuration and identify the main structural orientation of the Tertiary-Cretaceous Formations within the Lake Sub-Basin.

1.1 Geological Setting

The southeast corner of the Mega-Chad basin comprises the Nigeria-Chad basin, sometimes referred to as the Borno basin. It is considered a failed arm of the triple-junction rift system that emerged during the Early Cretaceous, allowing the separation of the South American and African continents as the South Atlantic Ocean began to form [22-25]. As the South Atlantic opened and regional extension occurred in a northeast-southwest direction, NNW-SSE-oriented extensional basins developed extensively in both East-Central Africa, such as Sudan, and West Africa, such as Niger. Together with related trans-tensional basins in Central Africa, these basins were connected by the dextral fault structure of the Central-African Shear Zone, as shown in Figure 1 [26]. The Borno Basin is the northeastern extension of the Benue Trough, characterised by an overall NE-SW trend orientation [27]. Three sub-basins make up the basin: Lake/Baga in the northeast, Maiduguri, and Gubio in the southwest. The southwestern slope of the Termit-Agadem basins in Niger and Chad is similar to the northeastern sub-basin. In contrast, the southwest sub-basins are frequently referred to as the Upper Benue Trough.

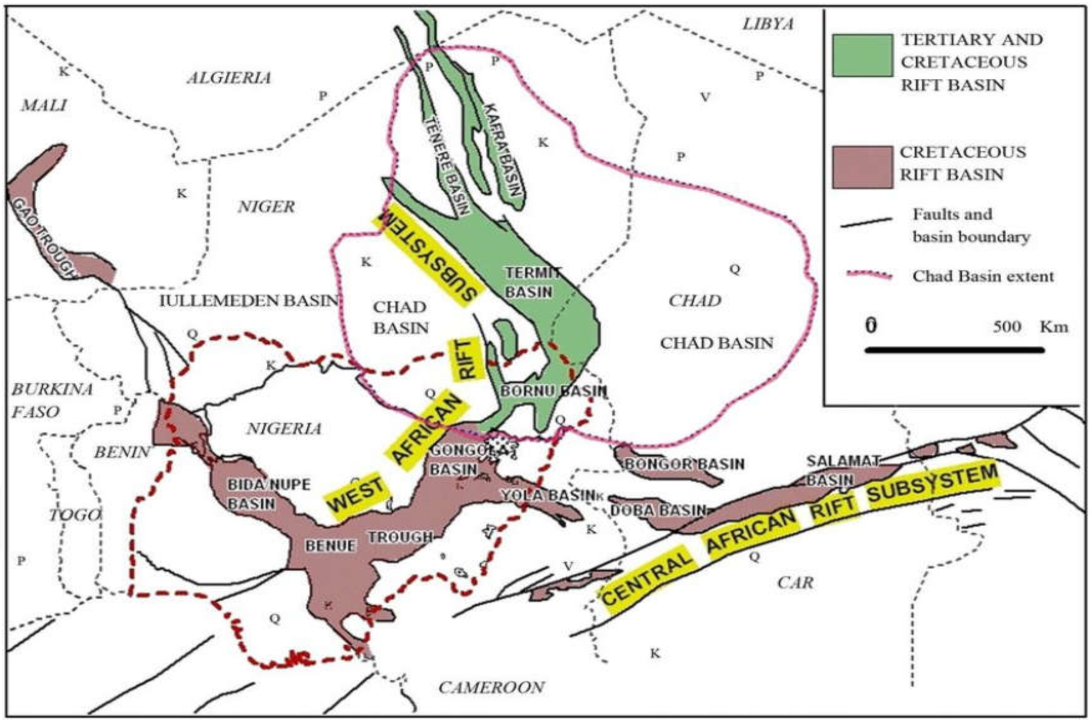

Fig. 1 Regional map of Chad and other neighbouring basins [26]

Primarily formed in the Early Cretaceous, the Borno basin is part of the larger Mesozoic-Tertiary rift system in Africa. Large-scale clastic sediment deposition, extending over several kilometres and dating back to the Lower Cretaceous period, occurred during the rifting phase, with mainly lacustrine shales and sandstones. Before the active rifting phase, during the late Albian epoch, a period of thermal subsidence occurred, which facilitated the progradation of substantial deltaic and fluvial sediments [26, 28, 29]. Throughout the Santonian period, there were isolated instances of compressional inversion, likely related to fluctuations in relative plate motion, especially between the African and European plates [30, 31]. The Late Cretaceous to Early Tertiary period was characterised by two distinct extension cycles and subsidence phases following a widespread Santonian unconformity. Ultimately, across West Africa, regional uplift was dominant during the Miocene era.

1.2 Tectonic Setting

Both the Borno Basin and Benue Trough share a genetic relationship and are regarded as key parts of the same NE-SW rift system. In both basins, sedimentation is believed to have begun during the

Albian period. Their fault arrangements are characterised by a zigzag pattern, resulting from tensionally driven basement tectonics. Other fault trends, such as NW-SE and NNE-SSW, are also observed, although the dominant trend remains NE-SW [27, 32]. The basin's common features include hidden hills, grabens, basement horsts, and intrusive volcanic structures. Most faults within the sub-basins involve the basement and end beneath a localised angular unconformity marking the Cretaceous–Tertiary boundary. Strike-slip movements along these faults can generate compressional folds resembling drag folds or positive "flower" structures [33, 34]. The Maiduguri sub-basin contains folds primarily limited to its deeper areas. These folds generally exhibit simple symmetrical shapes, with related complex structures being less frequent. The subsurface extensions of volcanic outcrops at the southeast edge of the Maiduguri sub-basin are believed to be intrusions that further influence the structural complexity. A direct correlation exists between the seismic sequences from seismic reflection records and the basin's well-established stratigraphy. Based on the seismically derived stratigraphy and observable structural features, the basin's rift origin has been identified. Within this sub-basin, the Cretaceous-Tertiary boundary appears as an angular unconformity on the seismic section, with most faults originating from the basement and ending at this boundary [27].

1.3 Stratigraphic Setting

The sedimentary unit, comprising marine and continental sediments, is typically very thick, locally reaching over 10,000 metres, with an average of 5,000 to 6,000 metres [35]. Most of these units are associated with the rift episodes. However, the thickness of post-rift sediments in Late Tertiary to Recent depocentres can be as much as 3,000 to 4,000 metres [26]. The studied area is located where the subsystems of Central and West Africa converge in the Maiduguri Lake sub-basins of the Borno basin, within a triple junction involving SW-NE (Benue), NW-SE (Agadem), and WSW-ENE (Doseo) orientations. The stratigraphic framework discussed by several researchers includes the following lithostratigraphic units from bottom to top as shown in Figure 2 [11, 16, 25-29].

The stratigraphy of the Borno Basin comprises a succession of Cretaceous to Tertiary formations beginning with the Pre-Bima unit, which unconformably overlies the crystalline basement and includes the Lower, Middle, and Upper Bima sandstones ranging from irregular, tectonically influenced deposits up to 1500 m thick in the lower part to more uniform, cross-bedded fluviatile sandstones averaging 500 m in the upper section [30, 32, 34, 40]. Overlying this is the Albo–Cenomanian Bima Formation, a poorly sorted medium-to coarse-grained sandstone sequence reaching 3050 m in thickness and deposited in variable continental to deltaic environments [11, 36, 41]. The subsequent Turonian Gongila Formation consists of cyclic shallow-marine deposits of fossiliferous limestone, shale, and sandstone with an average thickness of 420 m [18, 26]. This is followed by the Campanian-Santonian Fika Formation, dominated by ammonite-rich marine shale interbedded with thin limestone and siltstone layers and averaging 430 m in thickness [16, 39]. The Maastrichtian Gombe Formation represents a regressive estuarine-deltaic sequence of coal, sandstone, clay and siltstone, averaging 350 m thick, though absent in several wells due to post-Cretaceous erosion [42]. The overlying Paleocene Kerri-Kerri Formation comprises flat-lying continental sandstones, grits, and clays about 300 m thick [43]. At the same time, the Pleistocene Chad Formation forms the youngest unit with alternating sandy-clayey and arenaceous deposits across the basin [44].

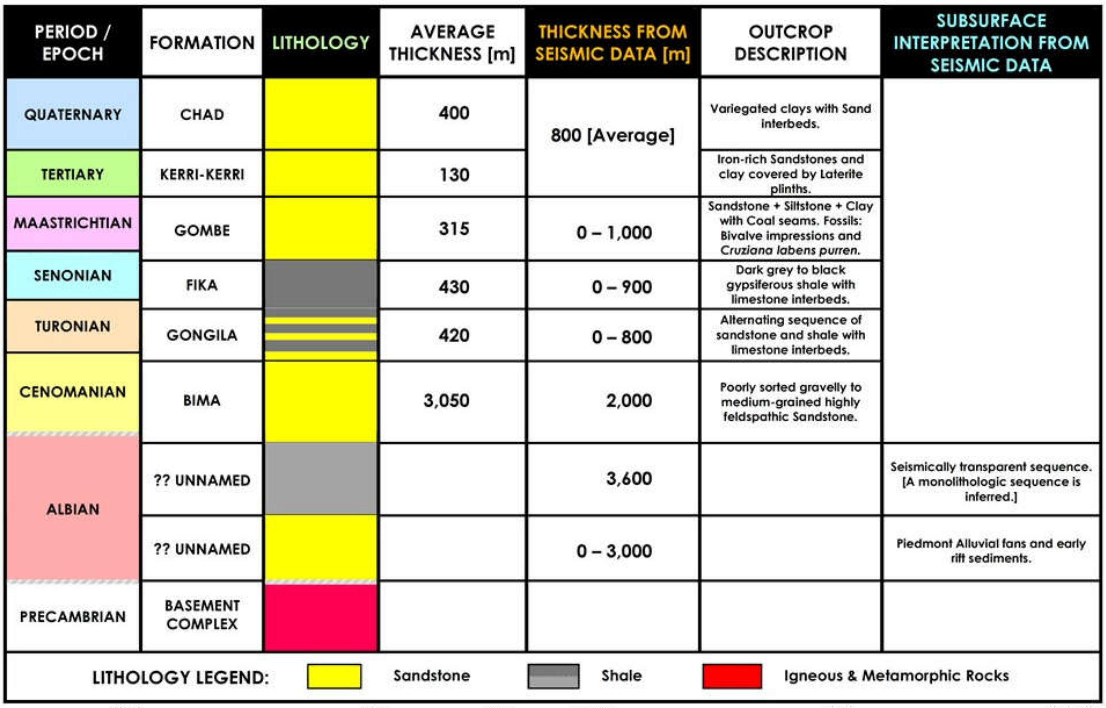

Fig. 2 Generalized stratigraphic cross-section of Borno basin, North-Eastern Nigeria, adopted by [45] modified by [27]

1.4 Hydrocarbon Potential of Borno Basin

Several rifted basins within the Mega-Chad basin produce hydrocarbons commercially, including the Bongor, Doba, and Doseo basins in Chad, as well as the Agadem and Kafra basins in Niger. Gas shows in the Ziye-1, Wadi-1, and Kinasar-1 wells, drilled in the Bornu Basin, indicate the presence of hydrocarbons [16, 36]. Recently, hydrocarbon was also found in the Kolmani River II well. For the Borno Basin Prospectivity study, assessing the accessibility and spatial overlap of key geological elements such as caprock, source rock, migration, reservoir, and trap is important for petroleum accumulation.

Geochemical studies indicate that nearly 90% of the organic matter in the Borno Basin is amorphous and marine-derived, with the Gongila and Fika Formations providing sufficient organic richness to function as effective source rocks, whereas the Bima Formation remains organically lean and requires further assessment; pre-Bima lacustrine shales have also been proposed as a potential Lower Cretaceous source interval [10, 31, 35]. Reservoir quality is distributed across several sandstone and carbonate units, including intra-Fika sandstones in the Upper Cretaceous play and the Bima and Pre-Bima sandstones in the Lower Cretaceous play [35]. Trap development is strongly influenced by Santonian compressional tectonics, which produced growth faults, anticlines, horsts, grabens, intrusive-related closures, and various stratigraphic traps such as pinch-outs, channel fills, and lens-shaped bodies, with compaction, basin inversion, and sediment starvation further enhancing sub-basinward thinning and trap formation [46, 47]. Seal integrity is provided by regionally extensive shales, specifically the Gongila Formation shales, which act as the primary top seal for Lower Cretaceous reservoirs, and the thick Fika Formation shales, which seal Upper Cretaceous intra-Fika sandstones [35]. Hydrocarbon migration is controlled by the basin’s discontinuous fault architecture, which limits lateral movement and promotes vertical, fault-focused migration through deep-seated structures that may channel hydrocarbons from pre-Bima source intervals into overlying reservoirs, making fault-assisted migration and structural traps the dominant accumulation mechanisms in the Borno Basin.

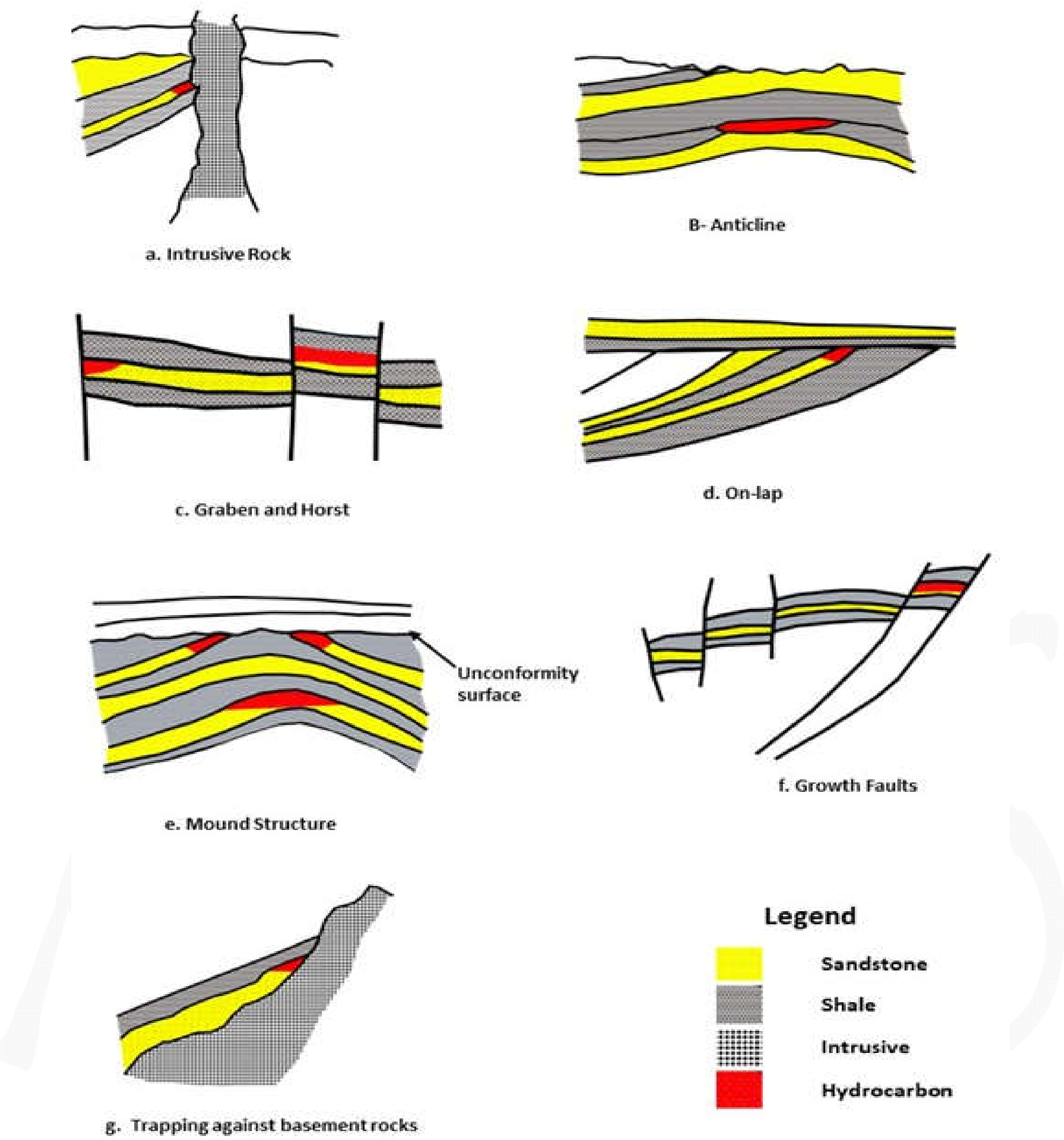

Fig. 3 Borno Basin Traps and Structural Styles construed from Seismic data modified from [47]

2.0 Materials and Method

2.1 Materials

The information used in this research included a 3D seismic volume covering 3891 km², with inlines (5047–6047) and crosslines (4885–7020) at a 25-meter bin size. The dominant frequency of the data is 16-17Hz, and the vertical resolution ranges from approximately 31.25 meters to 78.125 meters at shallow and deeper depths, respectively. Additionally, check shot data from Te-01, Wa-01, Da-01, Ji-01, and Sa-01, as well as seven well logs (Ak-01, Ft-01, Te-01, Wa-01, Da-01, Ji-01, and Sa-01) and biostratigraphic data, were used. All these data were loaded into relevant Petrel and Geographix software programs, and quality control and assurance measures were carried out, along with the harmonization of the data into clearly defined databases, as shown in Figure 4.

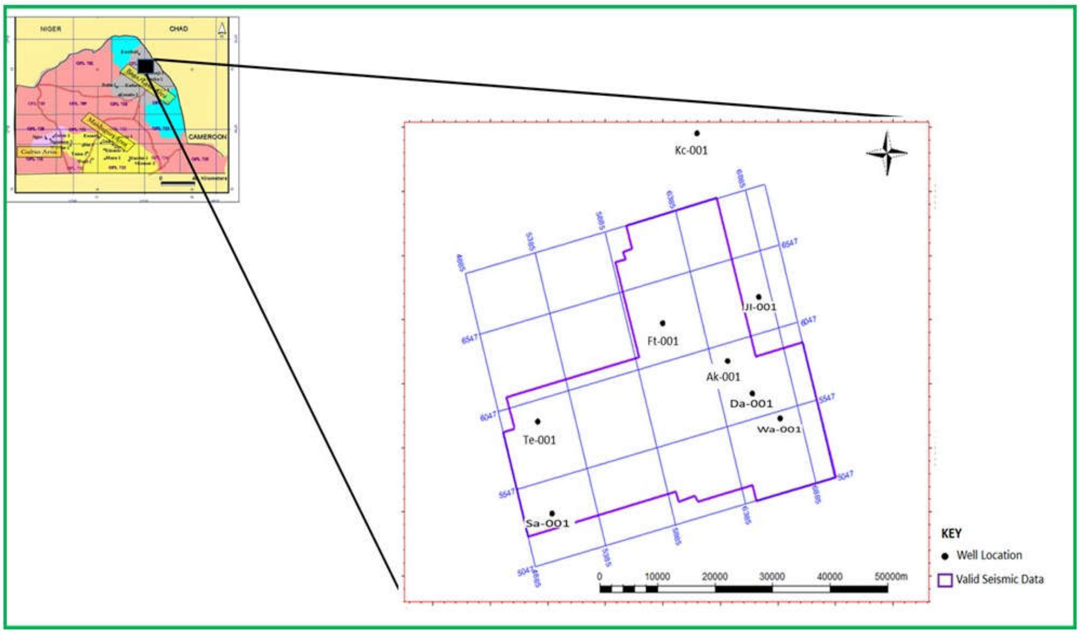

Fig. 4 3D Seismic survey base map of the study area

2.2 Methodology

A community-based, cross-sectional survey design was employed for this study. This design was appropriate for simultaneously assessing the prevalence of vaccine hesitancy, levels of knowledge, vaccine uptake rates, and identifying sociodemographic factors associated with vaccine hesitancy among the adult population.

2.2.1 Formation Delineation: using well logs and high-resolution biostratigraphic data, the top formations in the research area, Chad, Kerri-Kerri, Fika, Gongila, and Bima, were inferred for the regional correlation. The result of the biostratigraphy was based on the examination of ditch-cutting samples for Foraminifera, Palynomorphs, and Calcareous Nannofossils at 20-meter intervals in Da-01 well.

2.2.2 Well Correlation: Three steps were taken to correlate wells within the Lake sub-basin. The Da-1 well, the deepest by True Vertical Depth Subsea, is the most suitable well for correlation with other wells because it is assumed to have encountered more stratigraphic units in the study area. Therefore, it was used as a type well after a thorough investigation for correlation. Using Carter et al. (1963) and Avbovbo et al. (1986), the regional stratigraphic subdivision of the Chad Basin was divided into genetic stratigraphic orders as observed in the outcrop. Stratigraphic units were established within the well section displayed in Figure 5. The principles outlined by Baker Hughes were used to guide the subdivision of the log responses. [48]. Finally, other wells were correlated based on the extension of the stratigraphic subdivision of the Da-1 well, using similarities in the observed log responses. The correlation panel for the Sa-01, Te-01, Da-01, and Wa-01 wells is shown in Figure 6.

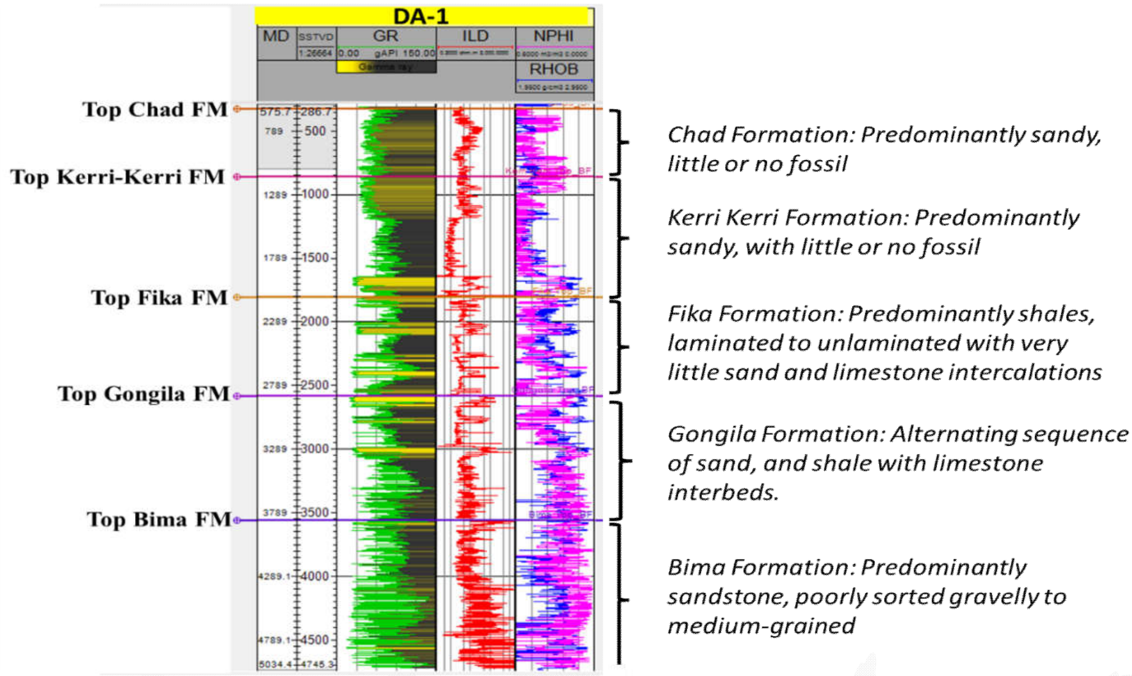

Fig. 5 Regional Stratigraphic (Type-well) Subdivision of Da-1 Well

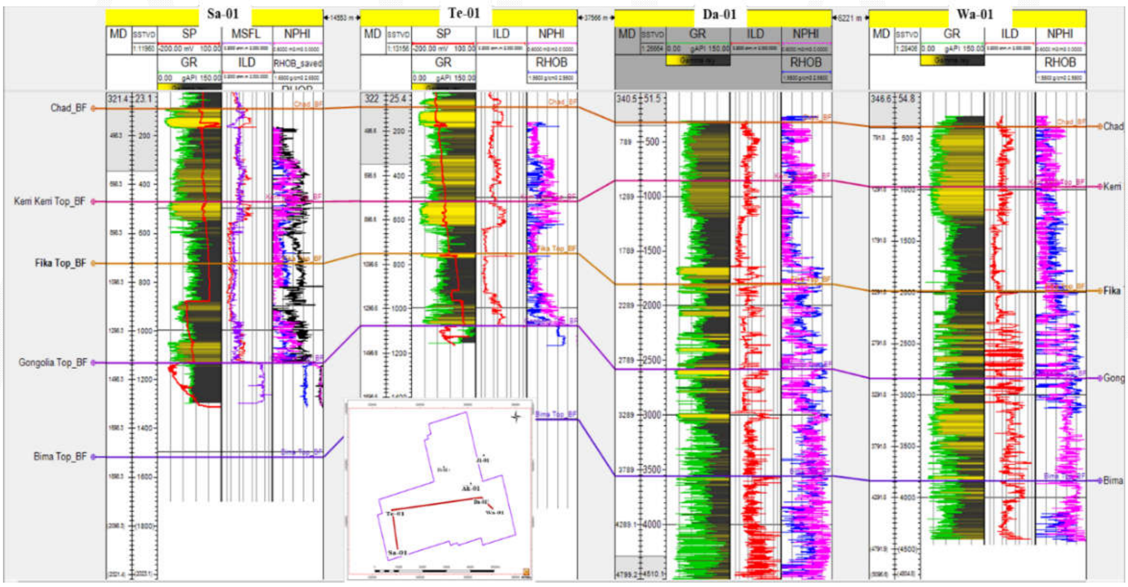

Fig. 6 Formation correlation across the wells of Block 1

The well-to-seismic tie was achieved by creating synthetic seismograms for four wells: Te-01, Wa-01, Da-01, and Sa-01, using sonic and density logs along with check-shot data from the relevant wells. The synthetic seismogram was generated using the seismic propagating wavelet derived from the seismic trace within a 50-meter radius of the wellbore. The wavelet was produced over a time range of 0.5 to 6.0 seconds with a sampling interval of 0.002 seconds. The wells satisfied the criteria for accurate calibration, with sonic and density logs recorded across the entire depth. Below is the well-to-seismic calibration of the Da-01 well as shown in Figure 7.

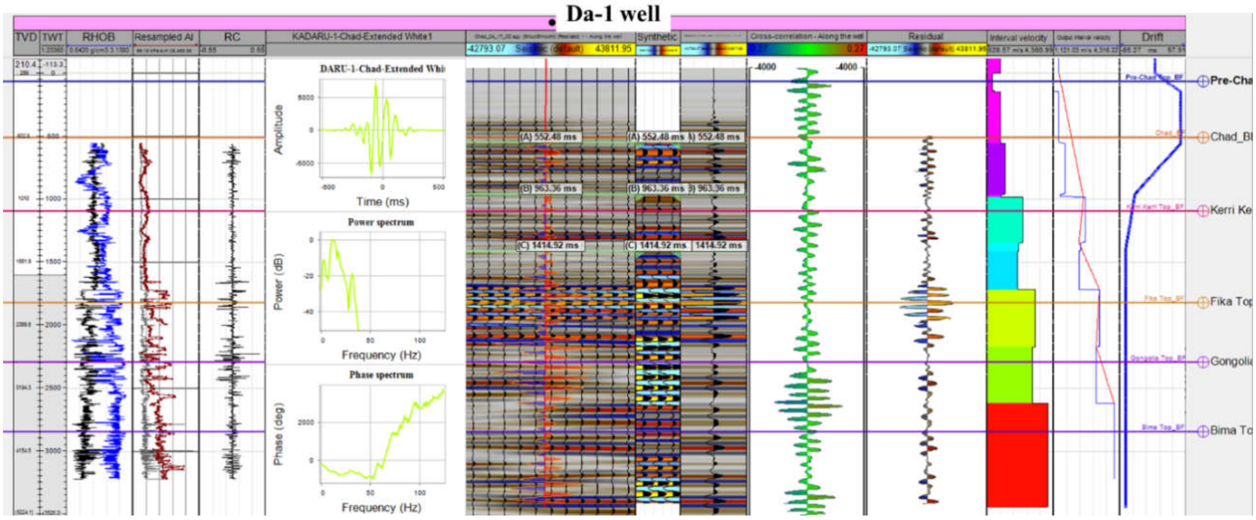

Fig. 7 Well to Seismic tie of Da-01well

Seismic interpretation: the top of the five formations, namely Chad, Kerri-Kerri, Fika, Gongila, and Bima, was confidently mapped due to their clear reflections on the seismic record. This interpretation involved mapping the zero-crossings between troughs and peaks, guided by the well-to-seismic tie. The analysis of seismic events on the workstation covered a time interval of 250-3000 milliseconds, corresponding to the formation tops at the well location. Fault and horizon interpretations were mapped on every fifth inline and crossline to delineate the structural framework and perform trend analysis of the study area. Figure 8 displays these interpretations, which helped in understanding the structural configuration and trends within the study area.

2.3 Time to depth conversion: The plot of time versus depth was generated from the check-shot data of all the available wells within the research area. The points were fitted using a polynomial line of best fit. The equation of the line generated by the curve was used to convert time maps into depth maps, as shown in Figure 9.

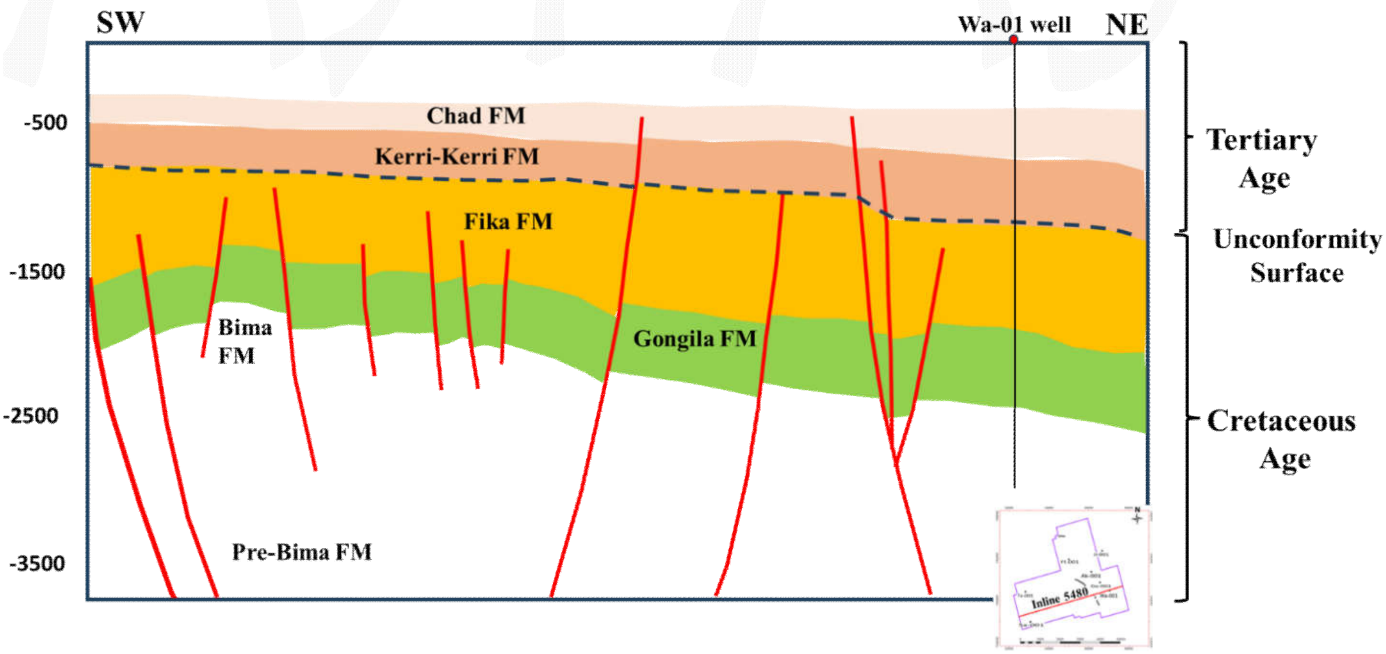

Fig. 8 An interpreted seismic section (inline 5650) showing fault framework

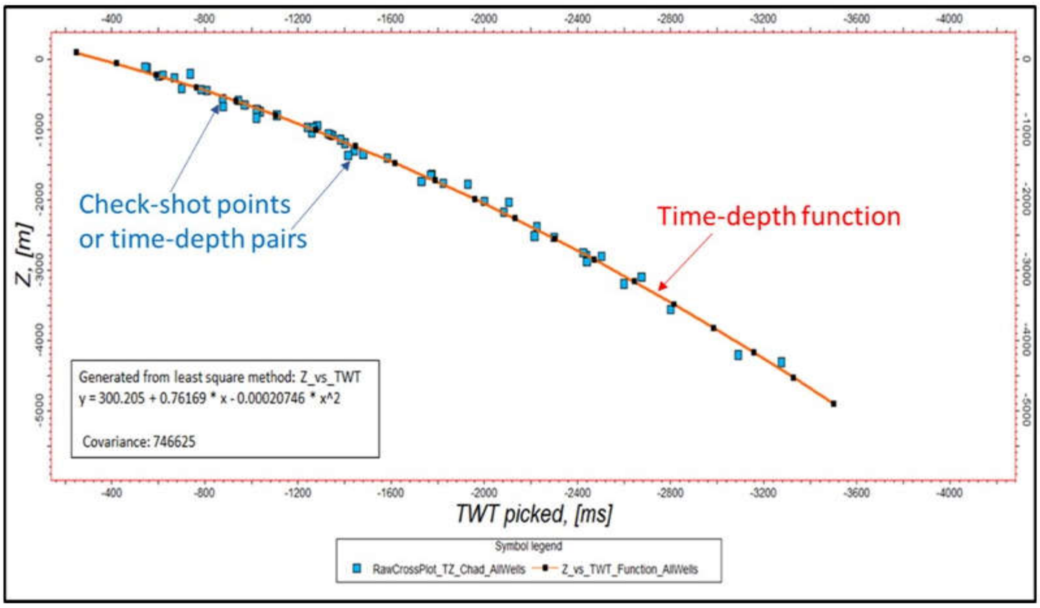

Fig. 9 Polynomial function line of best fit and corresponding equation for depth conversion

Moreover, seismic data quality control (QC) and assessment were performed to ensure reliability and accuracy prior to interpretation. The 3D seismic volume was evaluated for signal-to-noise ratio, amplitude consistency, and continuity of reflections across key horizons. QC procedures included trace editing, amplitude balancing, and filtering to suppress coherent and random noise, while preserving true geological features. Horizon and fault integrity were cross-checked against available well-log data to validate structural and stratigraphic continuity. These QC measures ensured that the seismic dataset provided a robust basis for reliable structural mapping, fault characterization, and reservoir delineation within the Lake Sub-Basin.

3.0 Results and Discussion

3.1 Seismic Data and Velocity Analysis Results

A high degree of reliability was achieved in interpreting the formation, based on the fairly good seismic data reflections. The results are presented as maps in Figure 10, the fault framework is shown in Figure 11, geological cross-sections are depicted in Figures 6 and 8, and velocity profiles are illustrated in Figure 9. To convert the structural time maps into depth equivalents, a polynomial line of best fit with a covariance of 746625 was used. The corresponding equation is stated in equation 1:

$$Y = 300.205 + 0.76169X - 0.00020746X^2 \quad (1)$$

Where: Y = depth, and X = two-way reflection time.

Using Equation 1 above, depth maps were generated for all time-structure maps in the Lake sub-basin of the Borno Basin, as shown in Figure 10.

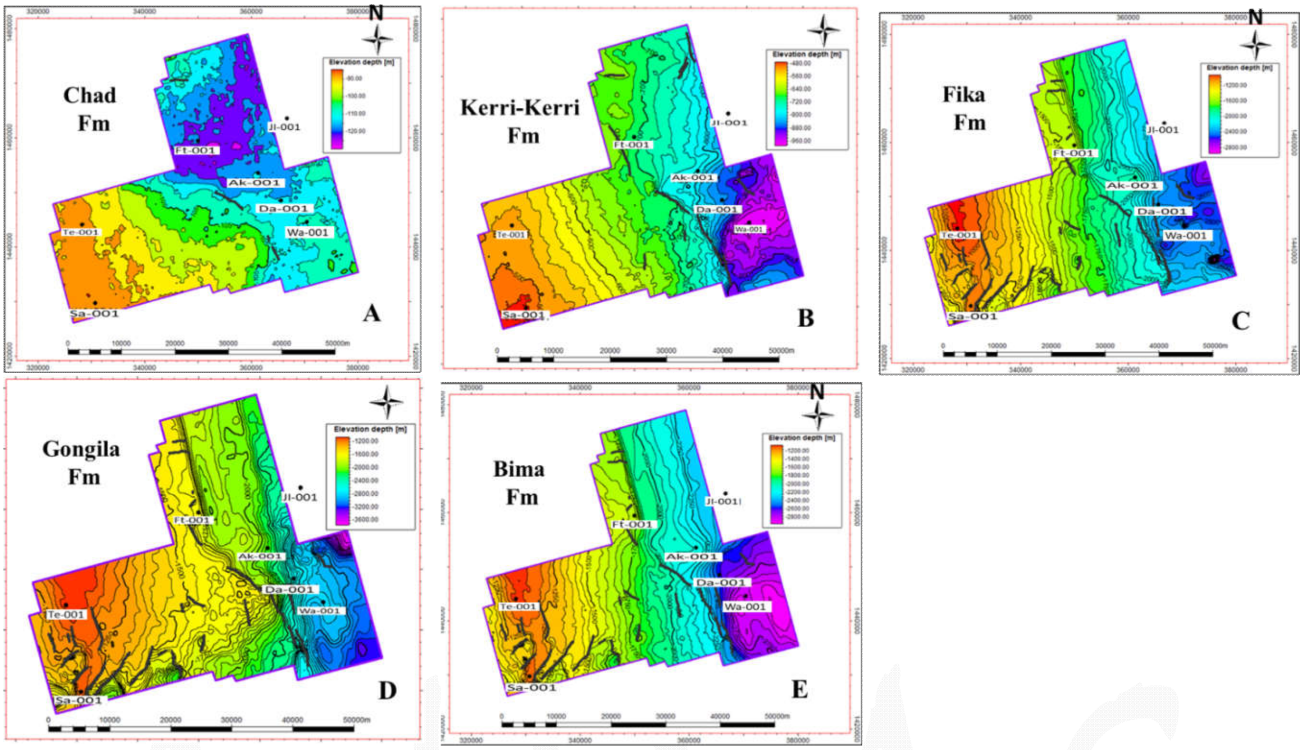

Fig. 10 Depth Structure Maps over the Top of Formations within Lake Sub-basin

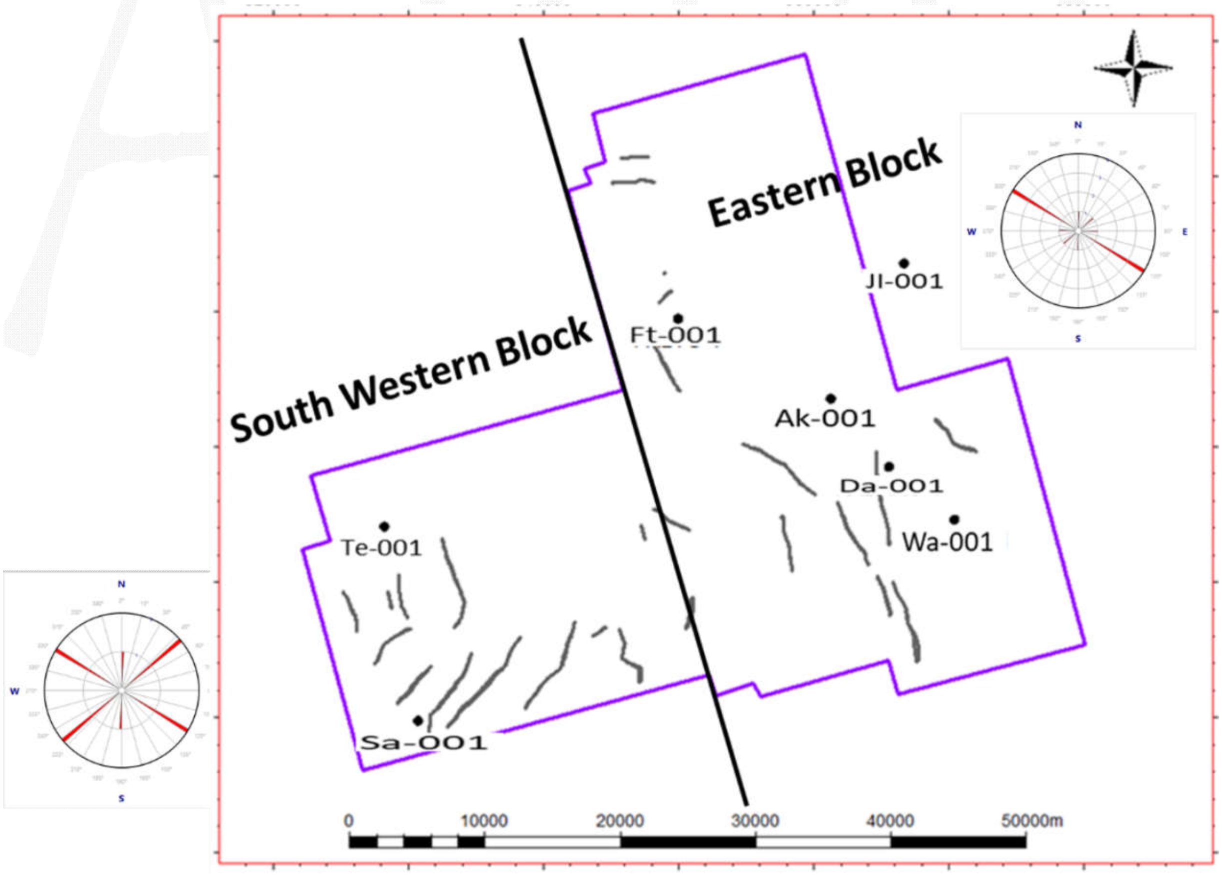

Fig. 11 Fault Framework Pattern and Rose diagrams showing the fault orientation analysis of the subdivision in the Study Area

3.2. Formation Thickness Analysis Results

Subsurface interpretation of the seismic data revealed both the structural and geological features, which are shown as expanded horizons on the seismic profiles. Conversely, faults are presented as discontinuities in these horizons. The mapped faults were categorized according to comparable deformation direction and geometry. It was noted that fault deformation planes were primarily linear, had a narrow range, and rarely extended into the Tertiary layers above. Both normal and reverse fault patterns were identified. Therefore, the faults within the Tertiary strata were concluded to be mostly stress-relieving faults.

3.2.1. Tertiary Strata

There is a general increase in sediment thickening from the West to the East within the Tertiary formations. Three fault orientations are documented in the Chad Formation, while four fault trends are recorded in the Kerri-Kerri Formation. All of the faults, however, are confined to the easternmost region. The thickest part of the formation is observed in the northern and eastern sections of the research area, with a peak near the Wa-01 well, which reached a maximum thickness of about 750 metres, whereas 380 metres of strata was recorded in the southwestern part. The NW-SE trending fault comprises 50% of the faults within this formation, while the N-S and E-W trends each account for 25% shown in Figures 8 and 10a.

The formation thickness in the Kerri-Kerri Formation generally follows a pattern, ranging from 350m at the Sa-01 well located in the southwestern part of the study area to over 1000 metres in the Southeastern section, reaching about 1200 metres at the N-E of Wa-01. Most of the faults within this formation trend in the NW-SE direction, constituting 55% of the total, with NE-SW and N-S directions accounting for 18% and 9%, respectively (Figures 8 and 10b).

3.2.2. Cretaceous Strata

Fika, Gongila and Bima Formations are the three recognised and interpreted Cretaceous strata. However, the deepest wells in the research area, TD within the Bima Formation, do not allow for the deciphering of the formation's base, which makes it impossible to estimate its thickness. The sediment thickness of the Fika Formation ranges from 300 metres at the eastern part of the Te-1 well to 1,000 metres in the northern and southeastern regions of the research area. An additional sediment thickness of about 800 metres was documented at the western fringe and the southwestern part of the asset. The sediment thickness of the Gongila Formation shows a similar trend to that of the overlying formation, ranging from 100 metres at the Wa-01 well to approximately 1200 metres in the north-central and southeastern parts of the research area. The fault pattern within these formations was analysed based on their respective positions in the study area. Within the Fika Formation, the most common fault orientations are NW-SE (50%) and NE-SW (46%), located at the eastern and southwestern parts of the block, respectively. Other fault orientations are detailed in Figure 10c. Three fault trends were identified within the Gongila Formation; however, the most common fault trends in the southwestern part are NW-SE and NE-SW, each recording 40%, and N-S, at 20%. In contrast, the NW-SE fault trend recorded 62% in the eastern section, while NE-SW and E-W recorded 23% and 15%, respectively, as displayed in Figure 10d. The fault pattern in the Bima Formation is similar to that of the Gongila Formation; nonetheless, NE-SW and NW-SE fault trends each account for 43%, and N-S accounts for 20% in the southwestern block. Meanwhile, the NW-SE fault trend dominates, accounting for 72% in the eastern section, with N-S at 18% and NE-SW at 9% as displayed in Figure 10e.

The integration of 3-D seismic and well data used in this study effectively revealed the detailed subsurface structural framework of the area. Generally, the interpreted seismic profiles indicate a gradual increase in sediment thickness of the Quaternary lithostratigraphic units from the west to the east within the Lake sub-basin. Simultaneously, there is an increase in the thickness of the Tertiary lithostratigraphic units (Chad and Kerri-Kerri) from west to east. However, the increase in thickness is less pronounced in the Tertiary formations than in the Cretaceous formations (Fika, Gongila, and Bima), where the thicknesses are greater. The Gombe Formation has been completely eroded in the study area, consistent with the findings of Moumouni and his team from some wells in the basin [6]. Consequently, the Kerri-Kerri Formation is deposited unconformably on the Fika Formation in this region.

Most of the faults mapped within the study area terminate beneath the angular unconformity surface that separates the Cretaceous strata below from the Tertiary strata above (Figure 8). Two major faults were documented within the Lake sub-basin: deep-sited synthetic faults and antithetic faults. A significant throw occurs in the deep-sited synthetic faults originating from the basement and affecting the sediments above it. They may be active, supporting vertical hydrocarbon conduits from the source rocks below and the accumulation in the shallow reservoirs. These dominant faults define the eastern and western boundaries of the depocentre, thereby dividing the research area into western and eastern compartments (Figure 8). The less dominant faults are the antithetic faults, which are confined within the sediment package. According to Mencos et al., it is believed to have developed in response to changes in the stress regime and a decreased likelihood of depositional or deformational origins [49].

4.3.1 Structural Configuration

Fault mapping is essential in identifying trap mechanisms, potential leak points, and migration pathways. It is also important to understand the structural setting of an area of interest. Faults influence the design of exploration and production wells, regulate sediment- and reservoir-depositional systems, serve as baffles or conduits for fluid flow, and are often the defining characteristics of structural traps. The structural style of the Borno Basin was applied to the interpretation of faults, in line with Avbovbo and his team's findings in the Maiduguri sub-basin, where two fault arrangements were deciphered in plan view. The four major faults delineated within the Lake sub-basin are (Figures 8, 12, and 13):

- **i.** Laterally persistent, northwest-southeast-trending faults in some cases with a meander pattern characteristic of rift systems.
- **ii.** Laterally tenacious, northeast-southwest-trending faults with a zigzag shape typical of rift systems.
- iii. North-South trending faults and
- iv. East-west trending fault (located in the northern part of the study area).

In the sub-basin, the most common fault trend is NW-SE, accounting for 45%. Other recorded fault trends include E-W, N-S, and NE-SW, with frequencies of 7%, 21%, and 27%, respectively, as shown in Figures 11, 12, and 13. When dividing Block 1 into the South-Western and Eastern blocks, as shown on the structural framework map in Figure 11, three fault trends are identified in the former, with NE-SW being the dominant. In contrast, four fault trends in the latter, with NW-SE orientation, are predominant as shown in Figures 12 and 13. The fault orientation in the South-Western part of the study area resembles that of the Maiduguri sub-basin. This area functions as a transition zone of fault orientation between the Maiduguri and Lake sub-basins. Previous researchers of the Mega-Chad basin also identified NNW-SSE, E-W, NW-SE, and NE-SW trending faults using 2D seismic data and potential field methods [6, 50-53].

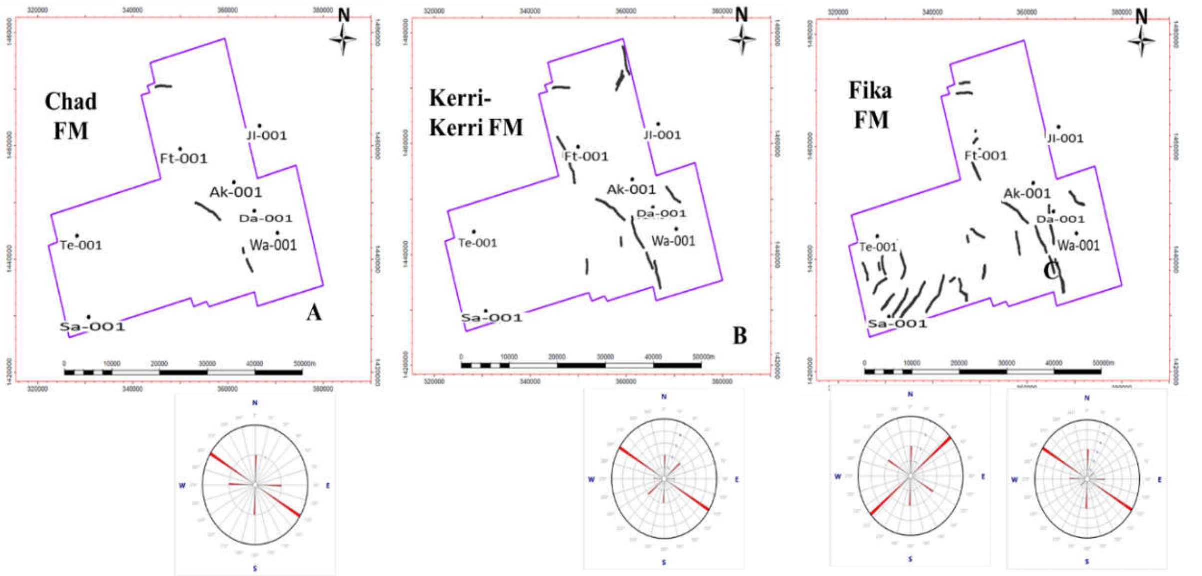

Fig. 12 Fault Pattern Analysis and rose diagrams of Chad, Kerri-Kerri and Fika Formations

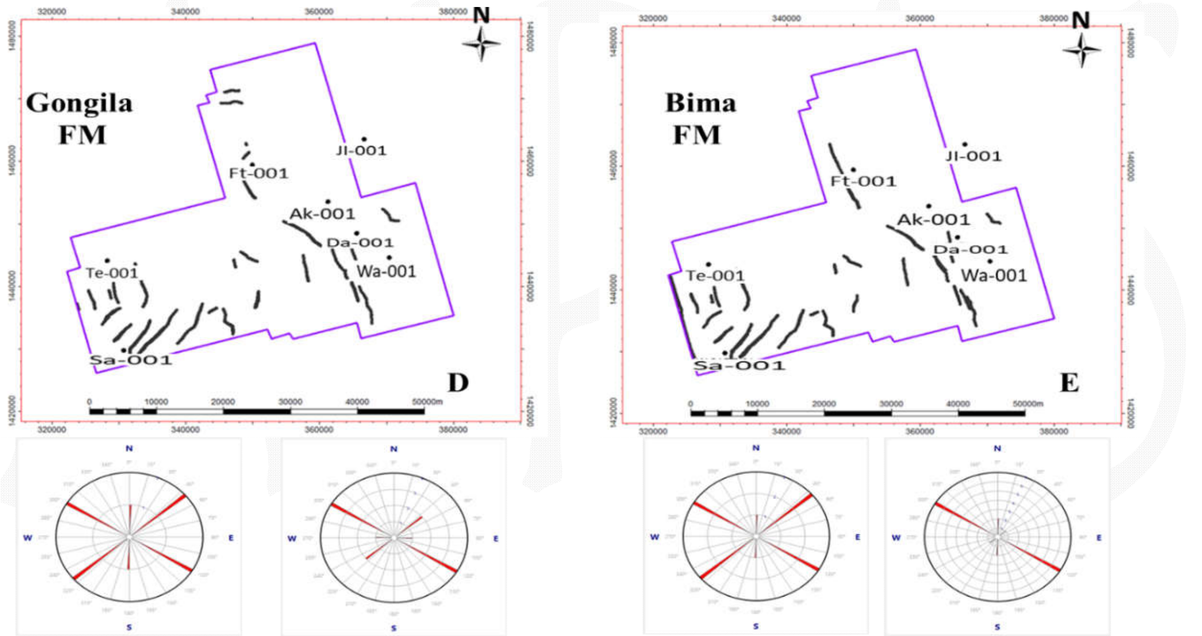

Fig. 13 Fault Pattern Analysis and rose diagrams of the Gongila and Bima Formations

4.3.2 Structural Interpretation

A comprehensive review of the study area's analysis reveals consistent tectonic activity and structural patterns. There is a regional dip and an increase in sediment thickness in the eastern part of the sub-basin. Fault synchronization is minimal, and fault patterns are highly distorted. As previously inferred, most faults are stress-relieving rather than syn-depositional. The fault throws are under 20 m but increase significantly below the Fika Formation (Figures 8, 10, and 12). Traps are rare in the Tertiary strata. The identified trapping structures are simple, faulted anticlines confined to the Fika Formation and other Cretaceous sediments. However, due to limited data, the full extent of the structure could not be determined. This trapping system resembles proven assets (blocks 1-7 series) in the Agadem basin in the Niger Republic. Given the paucity of extensive faults within the Lake sub-basin, fault-assisted traps may be scarce (Figure 10). It is believed that the primary source of sediment in the two depocentres originated mainly from the west to the east of the study area. Due to palaeogeomorphological imprints, sediment thickness increases from west to east, with thicker units in the east (Figures 8 and 10). Each depocentre is thought to be a separate entity with similar age, structural development, and sedimentation.

The structural high observed in the Cretaceous Formations trends roughly north-south and is separated by a fault, with the highest points at the Te-01 and Sa-01 wells in the southwestern part of the Lake sub-basin. This structural high may be related to tectonic upheaval or to deep-seated mobile shale under high pressure, which, in geological history, forces the shallower layers above to be uplifted. The influence of this tectonic uplift becomes less evident after the unconformity surface that separates the Cretaceous beneath from the Tertiary above (Figures 8 and 10).

Moreover, the integrated seismic interpretation of the Lake Sub-Basin reveals that simple anticlines, multi-directional fault networks, and variable sediment thickness create structurally and stratigraphically favorable traps, highlighting areas of enhanced hydrocarbon prospectivity. The identification of deep-seated synthetic faults and antithetic relief faults provides potential migration pathways from source intervals, while the overlying Gongila and Fika shales act as effective seals, ensuring trap integrity. These structural and stratigraphic configurations suggest that undrilled anticlines and fault-bounded closures, particularly where sediment packages are thick and laterally continuous, should be prioritized in future exploration campaigns. Targeting such structures with strategically placed appraisal wells could maximize the chances of hydrocarbon accumulation, reduce drilling risk, and optimize resource delineation. In general, the findings underscore the Lake Sub-Basin's potential as an underexplored frontier with high exploration value, providing a scientific framework to guide future drilling programs and investment in the Borno Basin.

4.0 Conclusion

This study revealed that Northwest–Southeast trending faults dominate the sub-basin with about 45% occurrence, followed by Northeast–Southwest (27%), North-South (21%), and East-West (7%) orientations. In contrast, additional East-West and North-South trending faults were recorded north of the Lake sub-basin. Two major fault systems were identified: deep-seated synthetic faults cutting across the basement and sediments, which likely serve as hydrocarbon migration pathways, and antithetic faults restricted to sedimentary packages. An unconformity surface separating the Fika Formation below and the Kerri-Kerri Formation above was also observed in the Lake sub-basin, consistent with previous findings in the Maiduguri sub-basin. Furthermore, sediment thickness generally increased eastward across the Lake sub-basin, and a few simple anticline structures were documented within the Cretaceous Formations, including the Fika, Gongila, and Bima Formations.

The Borno Basin is structurally complex, dominated by NW-SE faults with additional fault orientations, deep-seated synthetic and antithetic faults, and notable unconformities. The basin also shows increasing sediment thickness eastward and simple anticline structures within the Cretaceous formations, both of which underscore its hydrocarbon potential. From an exploration perspective, priority should be given to targeting fault-bounded closures, deep-seated fault conduits, and anticline structures where sediment accumulation is thickest, as these represent the most promising areas for hydrocarbon accumulation and appraisal drilling within this underexplored frontier basin.

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