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Stratigraphic Trap Configurations, Seismic Sequence and Facies Analyses of the 'Ekwai' Field: Implications for Hydrocarbon Exploration In The Niger Delta

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Abstract: *: Stratigraphic traps have become increasingly important exploration targets in the mature Niger Delta Basin because of the progressive depletion of conventional structural traps. This study utilized three-dimensional (3-D) seismic data, wireline logs, checkshot surveys, and well deviation data from three wells (KC1, KC2, and KC3) to characterize the stratigraphic trapping configuration, sequence stratigraphy, and seismic facies of the Ekwai Field in the eastern Niger Delta. The adopted workflow involved well-to-seismic correlation, structural interpretation, sequence stratigraphic analysis, seismic facies classification, and depositional environment interpretation. The results revealed stratigraphic traps associated with lateral facies changes, depositional pinch-outs, and five distinct channel-fill architectures (Types I–V). Among these, Channel Types II, III, and IV exhibit favourable seismic attributes, coarse-grained depositional characteristics, and high hydrocarbon prospectivity, whereas Types I and V are understood to be shale-dominated and less prospective. Sequence stratigraphic analysis established five sequence boundaries (SB1–SB5) and four maximum flooding surfaces (MFS1–MFS4), which were correlated across Wells KC1, KC2, and KC3 to define the depositional sequences and associated systems tracts. Seismic facies analysis identified distinct facies assemblages based on reflection configuration, continuity, amplitude, and frequency, enabling the interpretation of lithological variations, depositional energy, and sedimentary environments throughout the field. The integrated interpretation demonstrates that hydrocarbon accumulation within the Ekwai Field is controlled by the interaction of depositional architecture, sequence stratigraphy, and stratigraphic trapping mechanisms. The developed geological model enhances reservoir characterization, reduces exploration uncertainty, and provides a robust framework for hydrocarbon prospect evaluation and future field development within the eastern Niger Delta. The 3-D seismic data conducted in the Ekwai field of the eastern Niger Delta focused on understanding the stratigraphic framework. The main objectives were to identify trapping configurations of stratigraphic traps, and pinpoint channels with potential for hydrocarbon accumulation and analyse facies. The research utilized wireline logs, checkshot, and well deviation data from three wells. The methods included stratigraphic, seismic sequence and seismic facies analyses. Stratigraphic analysis uncovered traps resulting from facies changes, stratigraphic pinch-outs, and five channel fills categorized as types I, II, III, IV, and V. among these, channel types II, III, and IV exhibited promising hydrocarbon potential. In Sequence stratigraphy, four stratigraphic sequence boundaries (SBI, SB2, SB3, SB4 and SB5) and four intrasequence Maximum Flooding Surfaces (MFS1, MFS2, MFS3, and MFS4) were identified. SB1 and SB2 were correlated across KC1, KC2 and KC3 Wells. Facies analysis help to distinctively differentiate various facies units and internal reflective configurations, revealing the deposition environment.*

Keywords: *Channel-fill architecture, Hydrocarbon prospectivity, Niger Delta, Sequence stratigraphy, Stratigraphic traps*

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1.0 Introduction

The Niger Delta Basin is one of the world's most prolific hydrocarbon provinces, accounting for a substantial proportion of Nigeria's oil and gas reserves. For more than five decades, hydrocarbon exploration in the basin has primarily targeted structural traps, particularly rollover anticlines associated with growth faults, resulting in significant commercial discoveries. However, the progressive depletion of easily identifiable structural prospects has shifted exploration strategies toward subtle stratigraphic and combination traps, which are increasingly recognized as important targets for future hydrocarbon discoveries (Oyeyemi *et al.*, 2017; Osinowo & Ilukwe, 2018). Unlike structural traps, primarily depositional processes, lithofacies variations, erosional truncation, and diagenetic modifications control stratigraphic traps. Consequently, their identification requires the integration of high-resolution seismic interpretation, sequence stratigraphy, well-log analysis, and seismic facies characterization. As a result, high-resolution integrated studies have become essential for revealing the remaining hydrocarbon potential hidden within delicate stratigraphic variations across the basin (Emujakporue & Ngwueke, 2013). Recent advances in three-dimensional (3-D) seismic acquisition, seismic attribute analysis, and sequence stratigraphic modelling have significantly improved the ability to delineate subtle reservoir geometries and predict reservoir continuity within complex deltaic systems. These integrated techniques have become indispensable tools for reducing exploration uncertainty in mature petroleum basins such as the Niger Delta.

Sequence stratigraphy, when combined with 3-D seismic and well-log facies analyses, provides an all-inclusive structure for delineating these potential stratigraphic targets. Several researchers have demonstrated the effectiveness of integrating seismic interpretation with well-log correlation for reservoir characterization in the Niger Delta. Omosanya et al. (2018) highlighted the role of sequence boundaries and maximum flooding surfaces in predicting reservoir distribution, whereas Ali et al. (2019) demonstrated that seismic facies analysis improves the interpretation of depositional environments. Similarly, Fadipe et al. (2021) emphasized the importance of integrating sequence stratigraphy with seismic attributes for reducing exploration uncertainty. However, these regional studies were conducted predominantly in the western and central Niger Delta and emphasized broad structural or basin-scale trends; comparatively few have tested whether such sequence-stratigraphic and seismic-facies frameworks remain valid at the scale of an individual producing field within the eastern Coastal Swamp Depobelt, where structural style and depositional controls may differ substantially. This distinction underscores the limitation that motivates the present field-scale investigation.By subdividing sedimentary successions into genetically related assemblages bounded by chronostratigraphic surfaces such as sequence boundaries and maximum flooding surfaces, geoscientists can precisely forecast the spatial distribution of source rocks, reservoirs, and seals (Omosanya *et al*., 2018; Fadipe *et al*., 2021). Current developments in seismic facies interpretation have permitted greater precision in determining internal reflection configurations, which is critical for mapping various depositional environments from coastal plains to shallow marine shelves (Ali *et al*., 2019; Dim *et al*., 2020). This comprehensive method suggestively minimizes the exploration risks associated with lateral facies variations and stratigraphic pinch-outs.

Within the stratigraphic framework of the Niger Delta, specific depositional features such as

incised valley fills and submarine channel complexes represent exceptional exploration targets. The precise identification of these channelized systems depends on detailed seismic attribute and facies analysis to distinguish between varying internal geometries and lithological fills (Ajisafe & Ako, 2017). Recent studies underscore that different channel fills type exhibit unique porosity, permeability, and fluid retention properties, directly dictating their viability as hydrocarbon reservoirs (Sofolabo *et al*., 2025). Moreover, understanding the regional tectono-stratigraphic evolution provides vital context for how these channel complexes are disseminated and preserved within the broader deltaic succession (Opara *et al*., 2021; Ilesanmi *et al*., 2023). Recent investigations have further shown that channel morphology, internal architecture, and sediment fill exert significant controls on reservoir quality, hydrocarbon migration pathways, and trapping efficiency in deep-water and shallow-marine deltaic environments (Ang *et al*., 2026; Liu *et al*., 2025). Although numerous regional investigations have described the structural evolution, depositional environments, and petroleum systems of the Niger Delta, relatively few studies have integrated sequence stratigraphy, seismic facies analysis, and stratigraphic trap characterization at the scale of individual producing fields within the eastern Coastal Swamp Depobelt. Consequently, the spatial distribution of channel architectures, facies heterogeneity, and their influence on hydrocarbon accumulation within the Ekwai Field remain inadequately understood.

This lack of detailed field-scale characterization introduces uncertainty in reservoir prediction and exploration planning. The precise integration of facies and sequence-stratigraphic models for this specific field is necessary to target unexploited bypass zones effectively.

To address these knowledge gaps, this study integrates three-dimensional seismic data, wireline logs, checkshot surveys, and well deviation data acquired from wells KC1, KC2, and KC3 within the Ekwai Field. The specific objectives of this study are to: (i) establish a robust sequence-stratigraphic framework for the Ekwai Field; (ii) identify and characterize stratigraphic trapping configurations within the field; (iii) classify channel-fill architectures according to their hydrocarbon prospectivity; and (iv) interpret seismic facies to improve reservoir prediction within the study area.

The findings of this study will improve the understanding of depositional architecture and reservoir heterogeneity within the Ekwai Field. Furthermore, the integrated geological model developed from this investigation will reduce exploration risk, enhance reservoir characterization, optimize hydrocarbon prospect evaluation, and provide a methodological framework applicable to analogous fields across the Niger Delta Basin.

1.1 Geology of the Niger Delta

The Niger Delta is one of the world's largest Tertiary deltaic petroleum provinces, covering an area of approximately 70,000 km² and comprising a regressive sedimentary succession ranging from about 9,000 to 12,000 m in thickness (Evamy et al., 2013; Emujaporue & Ngwueke, 2013). The basin developed following the Early Cretaceous rifting that separated the African and South American plates, which initiated the opening of the South Atlantic Ocean. Subsequent large-scale sediment supply from the Niger–Benue river system resulted in continuous progradation of the delta toward the Gulf of Guinea, producing one of the most prolific hydrocarbon-bearing sedimentary basins in the world (Tuttle et al., 1999). The geological setting of the Niger Delta is presented in Fig. 1. The structural evolution, depositional history, and progressive basinward migration of sedimentation led to the development of five major depobelts, each representing a distinct phase of delta growth and hydrocarbon accumulation. These depobelts comprise the Northern Delta, Greater Ughelli, Central Swamp, Coastal Swamp, and Offshore depobelts (Short & Stauble, 1967; Doust & Omatsola, 1990; Nwajide, 2013). Each depobelt exhibits characteristic structural styles, sedimentary facies, and petroleum system elements that collectively control the distribution of hydrocarbon reservoirs and trapping mechanisms. The location of these depobelts and the position of the study area within the eastern Coastal Swamp Depobelt are illustrated in Fig. 2.

The stratigraphic succession of the Niger Delta is conventionally divided into three major lithostratigraphic formations (Fig. 3), namely the Benin, Agbada, and Akata Formations. The uppermost Benin Formation consists predominantly of continental to upper delta plain sands with minor clay intercalations and has an average thickness of approximately 200 m. These highly porous and permeable sands constitute the principal freshwater-bearing aquifers within the basin.

Beneath the Benin Formation lies the Agbada Formation, which consists of alternating sandstone and shale sequences deposited in paralic to shallow marine environments. The formation averages about 3,700 m in thickness and contains the principal hydrocarbon reservoirs of the Niger Delta. The sandstone units serve as excellent reservoir rocks, while the interbedded shales provide effective seals. Hydrocarbon accumulations within the Agbada Formation are commonly associated with rollover anticlines and growth-fault-related structural traps, although stratigraphic trapping mechanisms also play an increasingly important role (Doust & Omatsola, 1989; Onyia et al., 2002).

The lowermost Akata Formation comprises thick marine shales with occasional turbiditic sand bodies and attains an estimated thickness of about 21,000 ft (approximately 6,400 m). This formation is widely recognized as the principal source rock for hydrocarbons generated within the Niger Delta petroleum system.

Sequence stratigraphic investigations have further enhanced the understanding of depositional evolution and reservoir distribution within the basin. Ozumba (1999) identified the three principal systems tracts—Lowstand Systems Tract (LST), Transgressive Systems Tract (TST), and Highstand Systems Tract (HST)—in the western Niger Delta, providing a framework for interpreting depositional sequences and reservoir architecture. Similarly, Olayele et al. (2000) demonstrated that the Central Swamp Depobelt is characterized by stacked depositional cycles composed of lowstand slope fans and prograding wedge complexes, both of which constitute important reservoir targets owing to their favourable sand development and reservoir continuity. These sequence stratigraphic relationships have significantly improved the prediction of reservoir distribution, stratigraphic trapping configurations, and hydrocarbon prospectivity across the Niger Delta Basin.

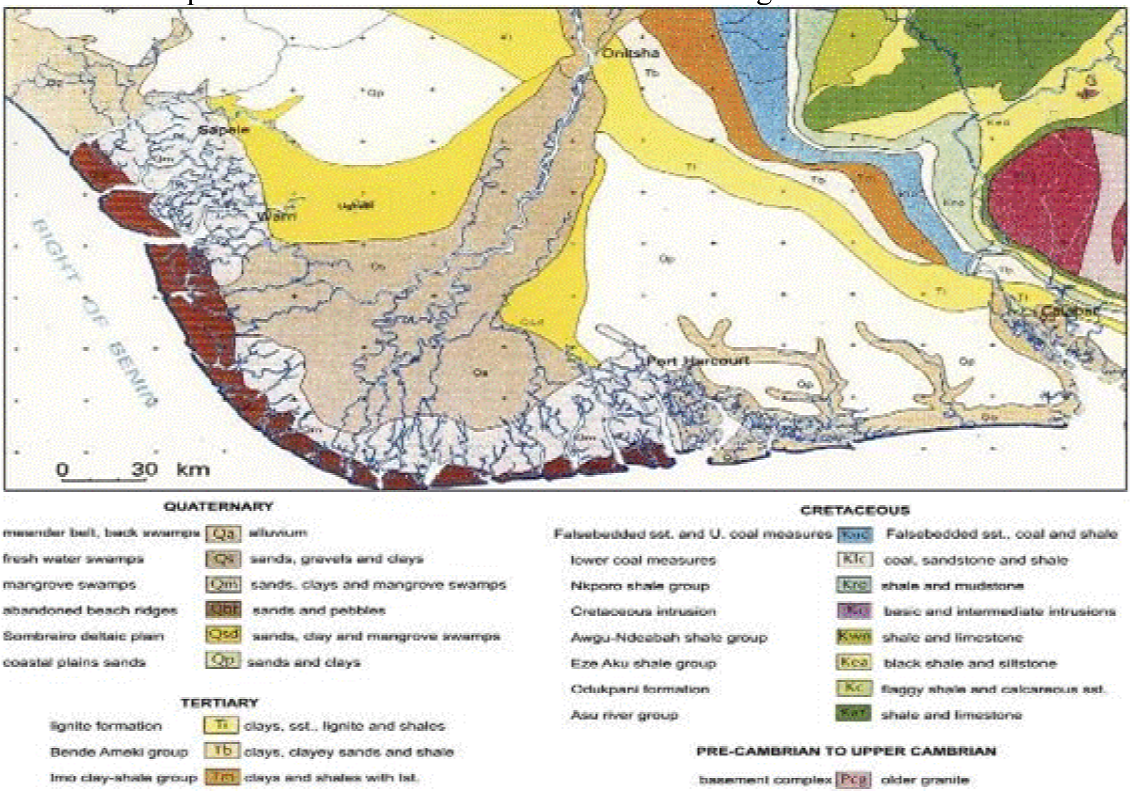


Fig. 1: Geologic map of Niger Delta. Source: Reijers, 2011

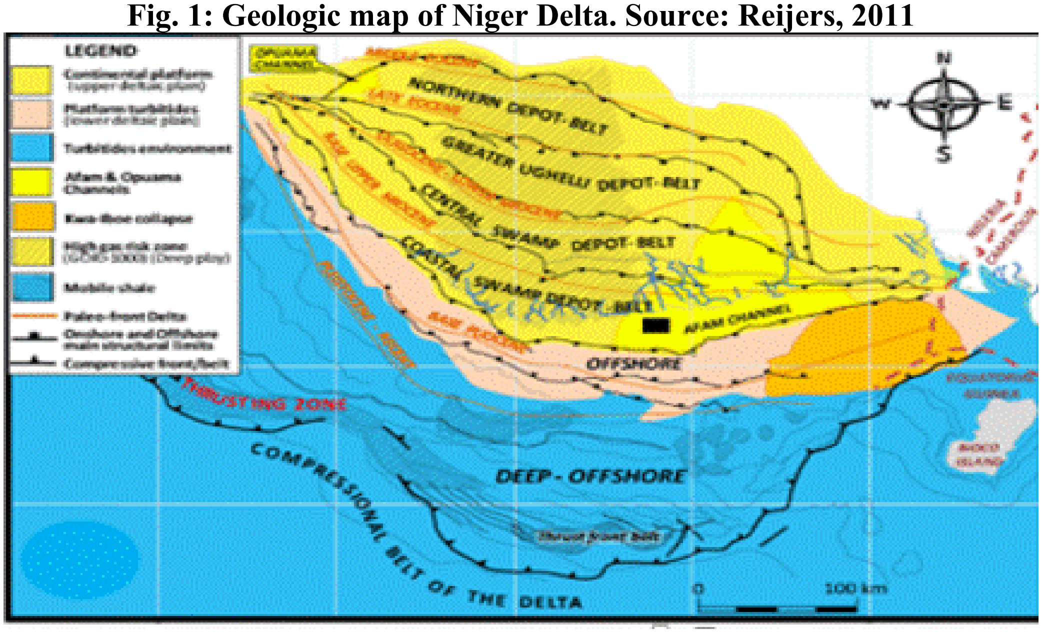


Fig. 2: The depobelts map of Niger Delta, and the location of study area in the eastern part of Coastal Swamp Depobelt. Source: Ebong *et al*., 2018.

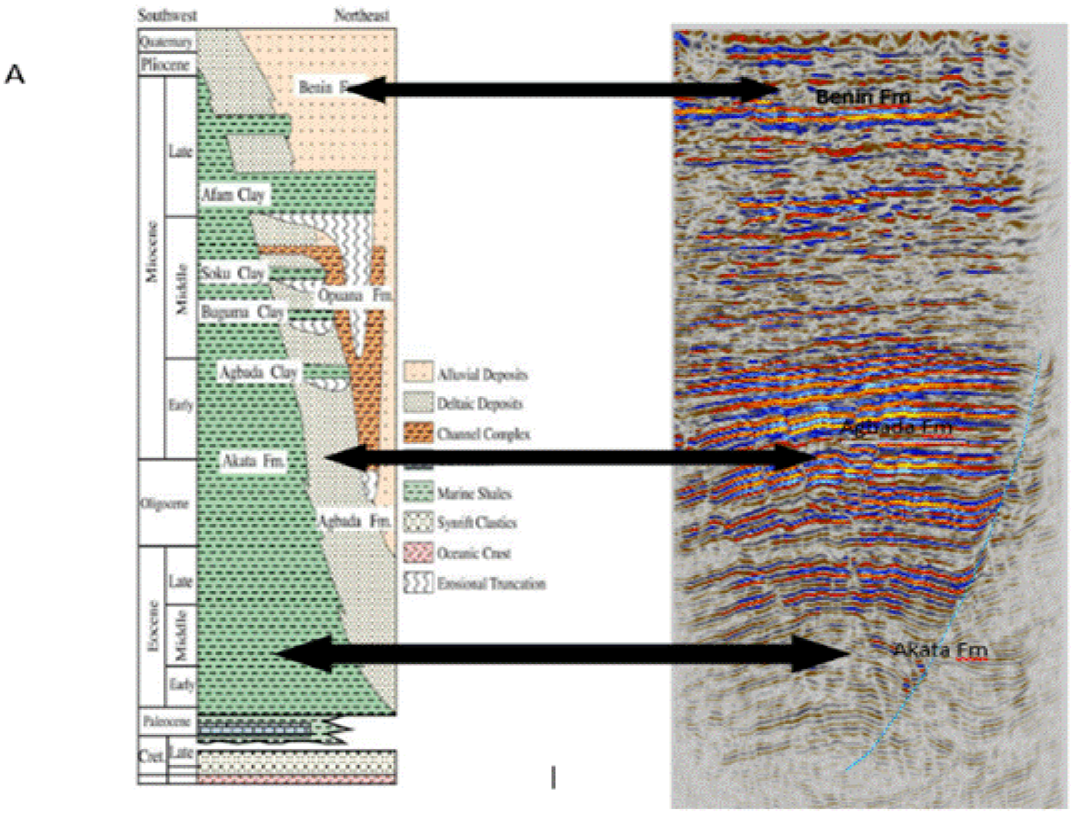


Fig. 3: Stratigraphic column

1.2 The Ekwai Field

The Ekwai Field is a producing hydrocarbon field situated within the eastern Coastal Swamp Depobelt of the Niger Delta Basin, southern Nigeria. Structurally, the field lies on the flank of a regional growth-fault system that has controlled the deposition and preservation of the Agbada Formation reservoir sands in the study area, with rollover anticlinal geometry and syn-depositional faulting exerting a first-order control on sediment thickness and reservoir distribution.

The field was selected for this investigation because, despite decades of hydrocarbon production from its structurally controlled reservoirs, its stratigraphic trapping potential and channel-fill architecture have not previously been categorized in detail. Earlier exploration and appraisal work in the field concentrated on structural closures associated with the bounding growth faults, leaving the more subtle stratigraphic elements of the reservoir system, such as facies changes, depositional pinch-outs, and channel-fill heterogeneity, comparatively underexplored. Given the progressive maturity of structural exploration in the Niger Delta generally, and in the Ekwai Field specifically, an integrated sequence-stratigraphic and seismic-facies study of the field is both geologically necessary and practically important for identifying remaining bypassed hydrocarbon volumes.

2.0 Materials and Methods

This study integrated wireline log data with three-dimensional (3-D) seismic data to characterize the stratigraphic trapping framework, establish the sequence stratigraphic architecture, and interpret the seismic facies of the Ekwai Field. The workflow followed the principles of seismic stratigraphy proposed by Vail et al. (1977), which integrates well-log interpretation with seismic reflection data to identify chronostratigraphic surfaces, depositional sequences, and sedimentary facies. Because biostratigraphic data were unavailable, the ages of the identified stratigraphic surfaces could not be constrained directly. Consequently, the interpretation relied on seismic reflection geometries, well-log signatures, and the stratigraphic relationships between key bounding surfaces.

The study commenced with comprehensive quality control of the seismic and well-log datasets to ensure data consistency and reliability. Stratigraphic horizons and reservoir intervals were first delineated from the wireline logs and subsequently correlated among the study wells. Checkshot data were then used to generate synthetic seismograms, enabling accurate well-to-seismic ties and the transfer of interpreted stratigraphic markers onto the seismic volume. Following the well-to-seismic calibration, structural interpretation was undertaken through fault mapping, after which sequence stratigraphic interpretation and seismic facies analysis were performed. The interpreted depositional architecture was subsequently used to infer depositional environments, lithological variations, and potential hydrocarbon trapping mechanisms.

Sequence stratigraphic interpretation was based primarily on the characteristic responses of wireline logs, particularly the gamma ray (GR), resistivity, and caliper logs. Reservoir intervals were identified by relatively low gamma-ray values that indicate clean sandstone units, whereas shale-rich intervals exhibited elevated gamma-ray responses. Sequence boundaries were interpreted from erosional surfaces and abrupt changes in log motifs associated with basinward facies shifts and depositional discontinuities. Maximum Flooding Surfaces (MFSs) were identified at intervals characterized by the highest gamma-ray values, representing condensed shale sections deposited during periods of maximum marine transgression (Fig. 4). These interpreted chronostratigraphic surfaces were subsequently correlated across the study wells and tied to the seismic data to establish the sequence stratigraphic framework and delineate depositional sequences throughout the field (Fig. 5).

To improve the recognition of subtle stratigraphic features, several seismic attribute volumes, including relative acoustic impedance, dip, iso-frequency, and genetic inversion, were analysed alongside the conventional seismic amplitude data. Specifically, relative acoustic impedance was used to differentiate sand-prone from shale-prone intervals based on impedance contrast. The dip attribute helped delineate fault trends, flexures, and the geometry of channel margins. Iso-frequency volumes highlighted subtle thickness variations and stratigraphic pinch-outs that are otherwise poorly resolved on conventional amplitude sections; and genetic inversion improved the lateral tracing of reservoir sand bodies away from well control. In combination, these attributes enhanced the visualization of lithological contrasts, stratigraphic discontinuities, channel geometries, and facies variations. The integrated interpretation facilitated the identification of stratigraphic trapping mechanisms associated with depositional pinch-outs, lateral facies transitions, and channel-fill complexes. Furthermore, seismic facies were classified based on reflection configuration, continuity, amplitude, frequency, and external geometry, providing valuable information on depositional processes, sedimentary environments, reservoir distribution, and hydrocarbon prospectivity within the Ekwai Field.

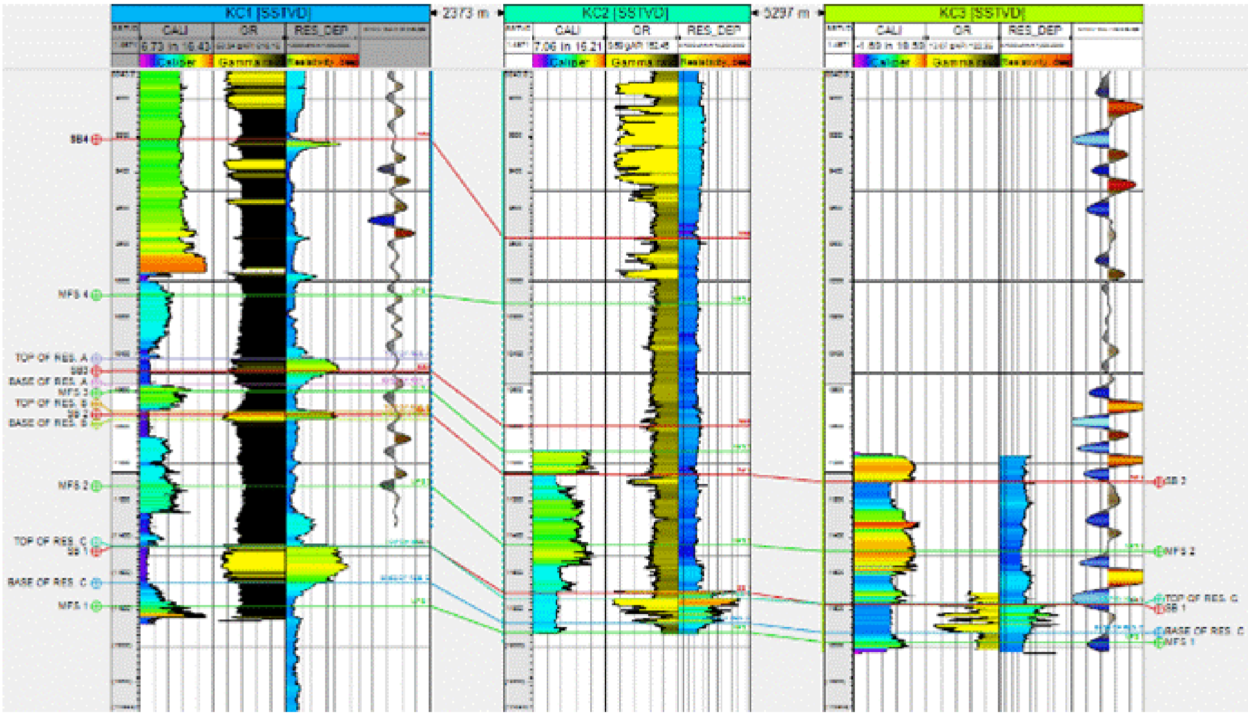


Fig. 4: Reservoir top and base, sequence boundaries and maximum flooding surfaces

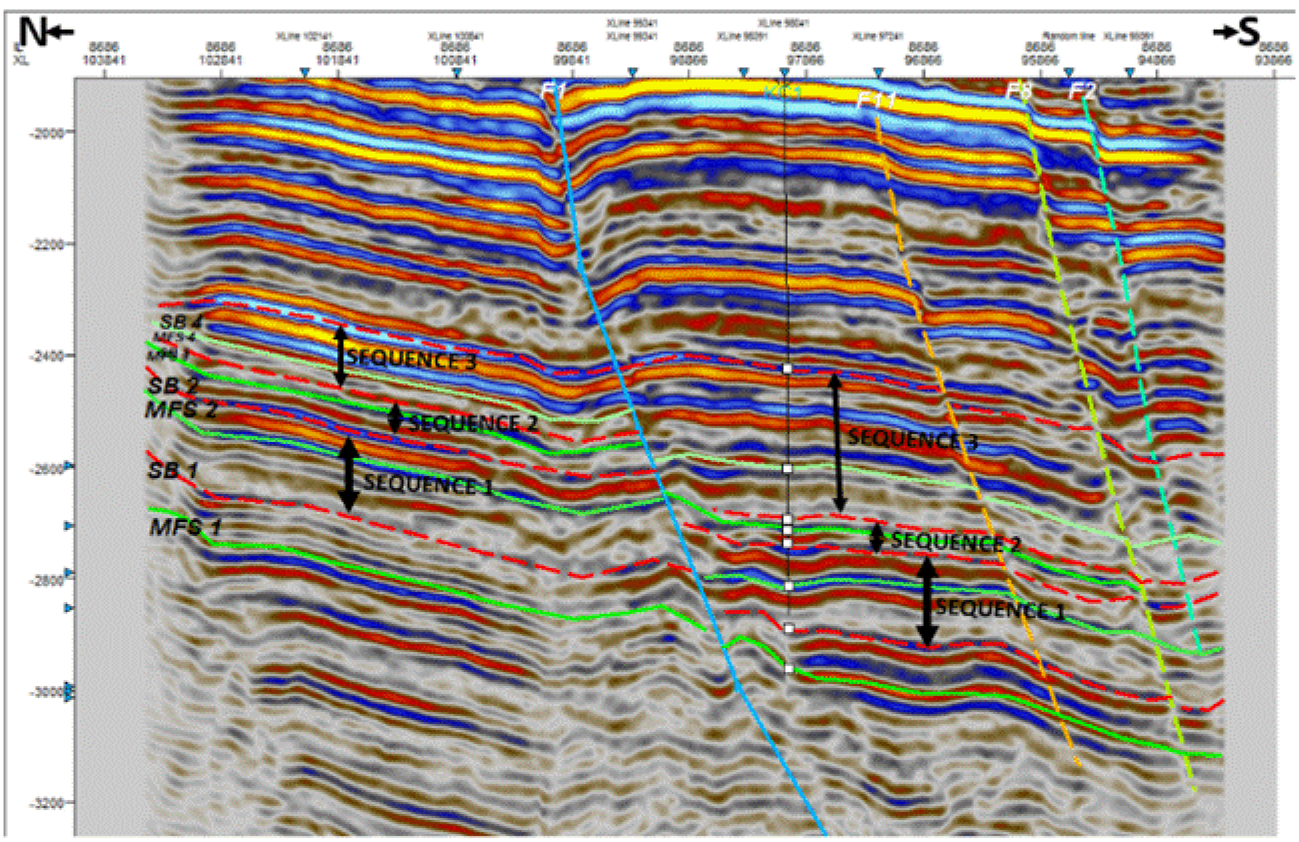


Fig. 5: The sequence boundaries (SB), Maximum Flooding Surface (MFS) on Well KC1

3.0 Results and Discussion

3.1 Identification of stratigraphic traps and hydrocarbon habitats.

The integrated interpretation of three-dimensional (3-D) seismic data, wireline logs, and sequence stratigraphic surfaces revealed distinct stratigraphic trapping configurations, channel-fill architectures, depositional sequences, and seismic facies across the Ekwai Field. These results provide valuable insights into the spatial distribution of potential hydrocarbon reservoirs and their controlling depositional processes. The occurrence of facies-change traps and depositional pinch-outs indicates that stratigraphic trapping (figures 6,7 & 8), plays a significant role in hydrocarbon accumulation within the Ekwai Field. These trapping styles are particularly attractive exploration targets because they are capable of retaining hydrocarbons in areas where structural closure is absent or poorly developed. Similar stratigraphic trapping mechanisms have been reported in other parts of the Niger Delta, emphasizing the growing importance of integrated seismic stratigraphic interpretation in mature petroleum provinces.Parallel to sub-parallel facies signify horizontal reflectors; divergent facies are described based on the inclination of the internal reflectors directed toward one direction. Mounded seismic facies shows a contorted discontinuous internal reflector as shown in Table 1.

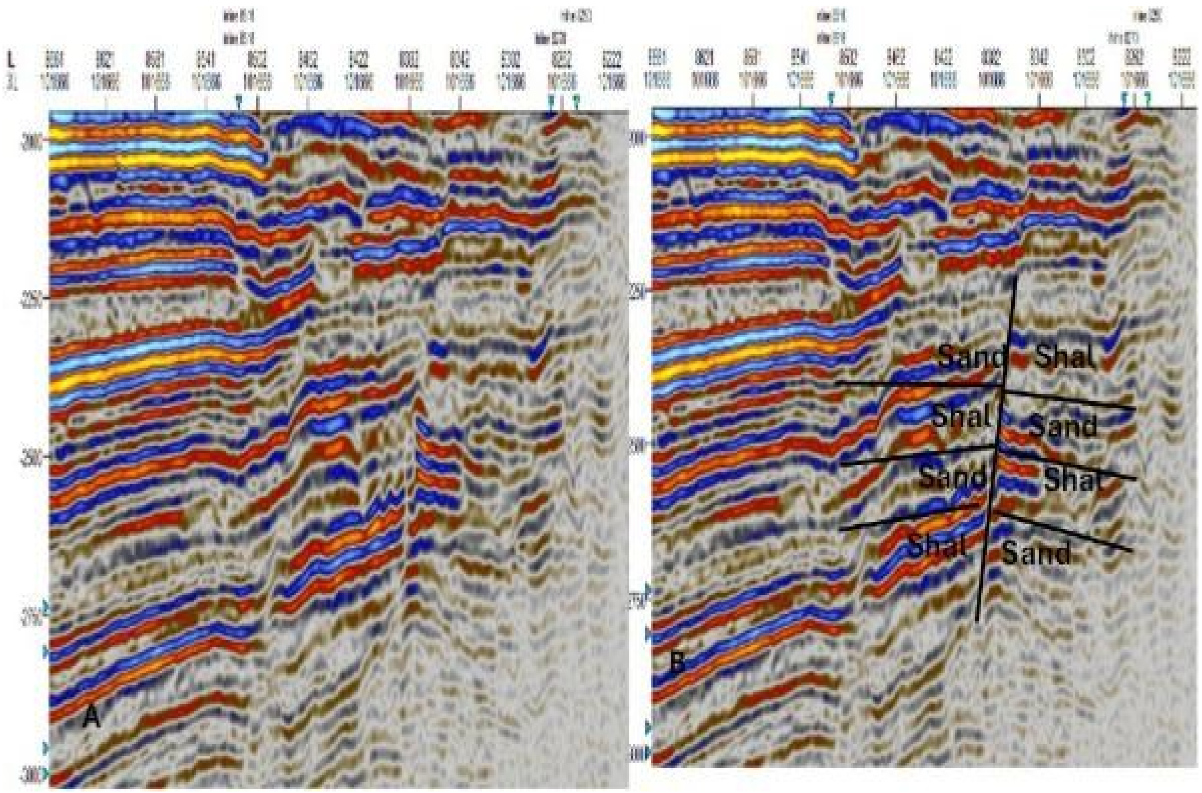


Fig. 6: (a) uninterpreted stratigraphic trap due to facies changes (b) interpreted stratigraphic traps due to facies changes

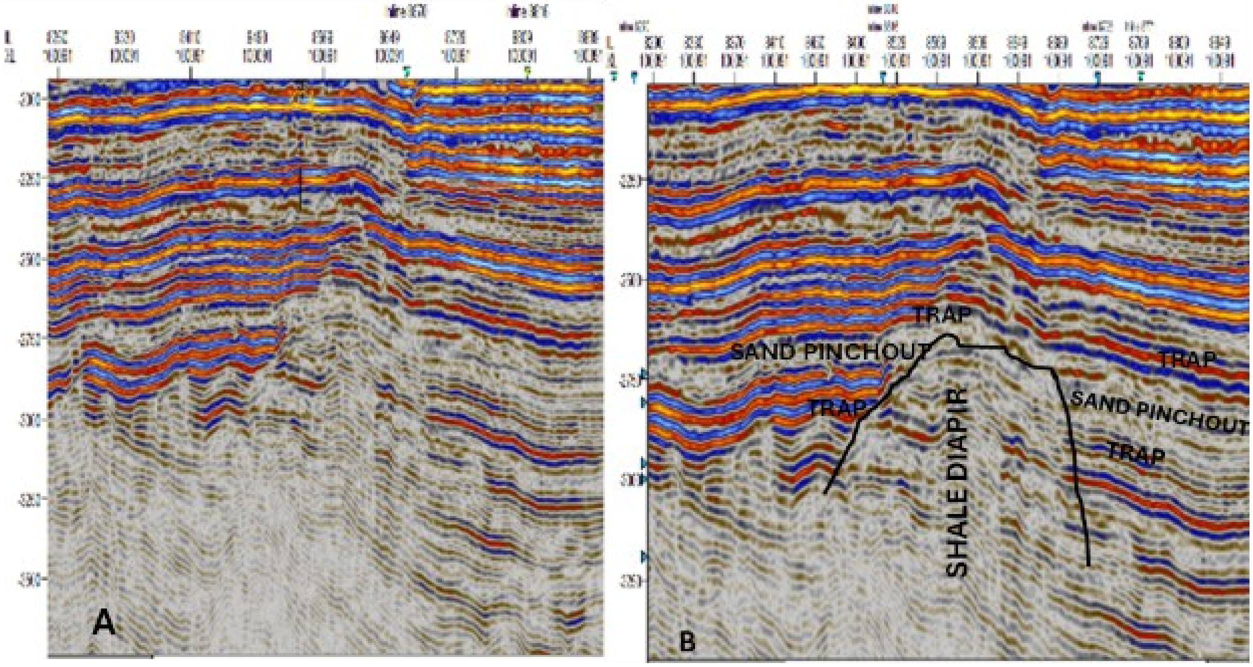


Fig. 7: (a) uninterpreted stratigraphic pinch-out and (b) interpreted stratigraphic pinch-out on a seismic section at a crossline 100091 on inline 8290-8849

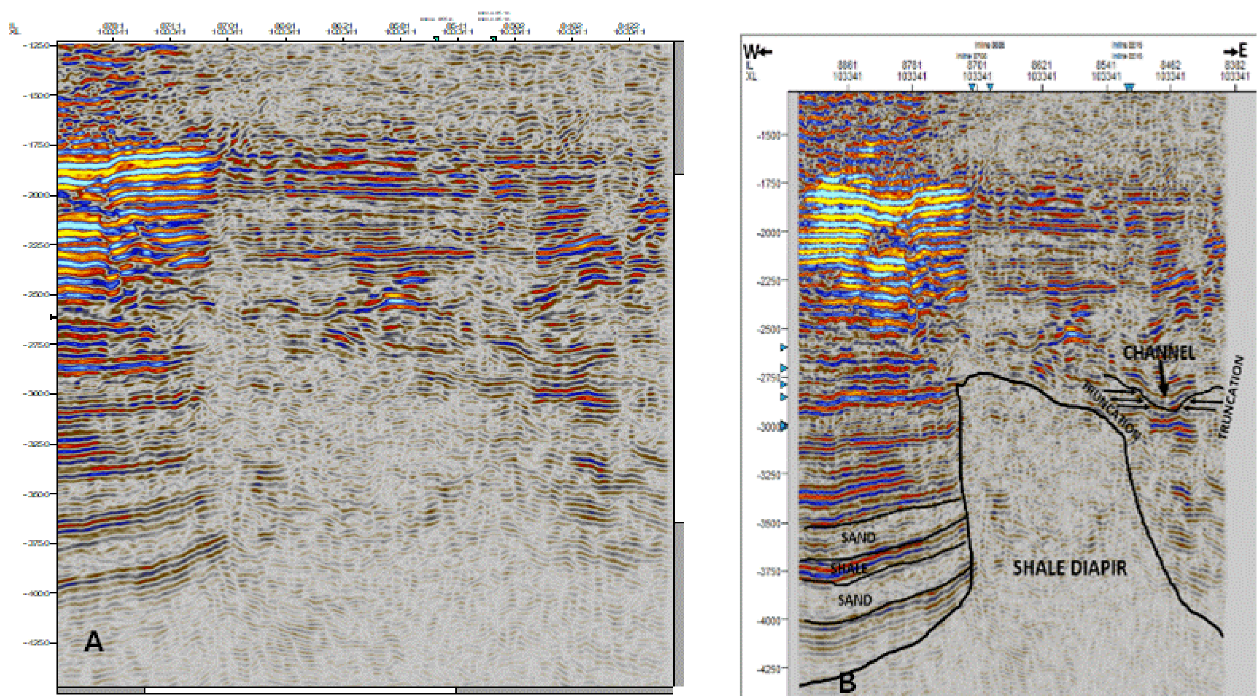


Fig. 8: seismic section at a crossline of 103341 on inline 8861- 8382 (a) Uninterpreted stratigraphic pinch-out and (b) interpreted stratigraphic pinch-out

3.2 Channel Identification and its potential for hydrocarbon

Five distinct channel-fill architectures were identified based on their seismic reflection configuration, amplitude, continuity, frequency, and external geometry. These channel types exhibit contrasting depositional characteristics that directly influence reservoir quality and hydrocarbon prospectivity.

TYPE I channel fill deposit appeared to have a feature of divergent or prograding fill pattern characterized by oblique and semi continuous reflection configuration, moderate to low amplitude and a high frequency (figure 9). The fill is observed to be thicker upstream and thinning basinward. The moderate to low amplitude reflectors dipping at a very low angle shows a characteristics feature of fine-grained deposits typical of an upper slope environment and thought to be shale or silt sand that are not considered as an exploration target .The mounded geometry, together with high-amplitude reflections, indicates deposition by high-density turbidity currents within basin-floor fan environments. These characteristics are commonly associated with laterally continuous, coarse-grained sandstone reservoirs possessing favourable porosity and permeability, making this channel type an attractive exploration target.

Type II is considered a mounded seismic facies unit. It shows a contorted discontinuous reflection configuration with the characteristic onlap, downlap and toplap truncations. The fill as shown in (Figure. 10) exhibits a high amplitude and high frequency internal reflectors typical of a basin floor environment with a coarse-grained sediments and is considered a good hydrocarbon target.

TYPE III- This was observed by it characteristic onlapping features with parallel and subparallel discontinuous reflectors. Geometrically is found to be broader and thicker basinward than shoreward. The low amplitude and high frequency facies typically graded landward indicating a massive sandstone deposits that can also be considered a good reservoir. The seismic section showing this channel fill are illustrated in (Figure 11). The widespread onlapping geometry suggests progressive basin infilling accompanied by relatively continuous sandstone deposition. Such depositional conditions favour the development of thick reservoir units capable of storing significant hydrocarbon volumes.

TYPE IV- This displays a downlapping progradational pattern with wavy parallel internal reflectors. The blocky continuous downlap, medium- high amplitude and high frequency constitute a representative features of a low prograding wedge (LPW) or basin floor fans (BFFS) characterized by sand and hence, could well thought out as a viable reservoir. The (Figure 12) shows seismic section of the channel fill. The observed downlapping clinoforms reflect active sediment progradation during periods of relative sea-level fall. Basin-floor fan deposits associated with this seismic facies are generally recognized as excellent stratigraphic reservoirs owing to their high net-to-gross ratio and good lateral continuity.

TYPE V- This seismic facies is seen to have a discontinuous parallel to low angle oblique or sigmoidal configuration. The strata downdip at the higher angle by downlap against the lower surface. This downlap as display in (Figure 13) depicts the outbuilding of sediments from shallow into deeper water with high amplitude and low frequency indicative of shelf margin and prograding slope environment. The characteristic facies unit is said to be shale prone and cannot be a good reservoir. Although this facies exhibits relatively high seismic amplitudes, its low-frequency response and interpreted shale dominance suggest poor reservoir quality. Consequently, this channel type is considered to have limited hydrocarbon potential despite its well-developed progradational geometry.

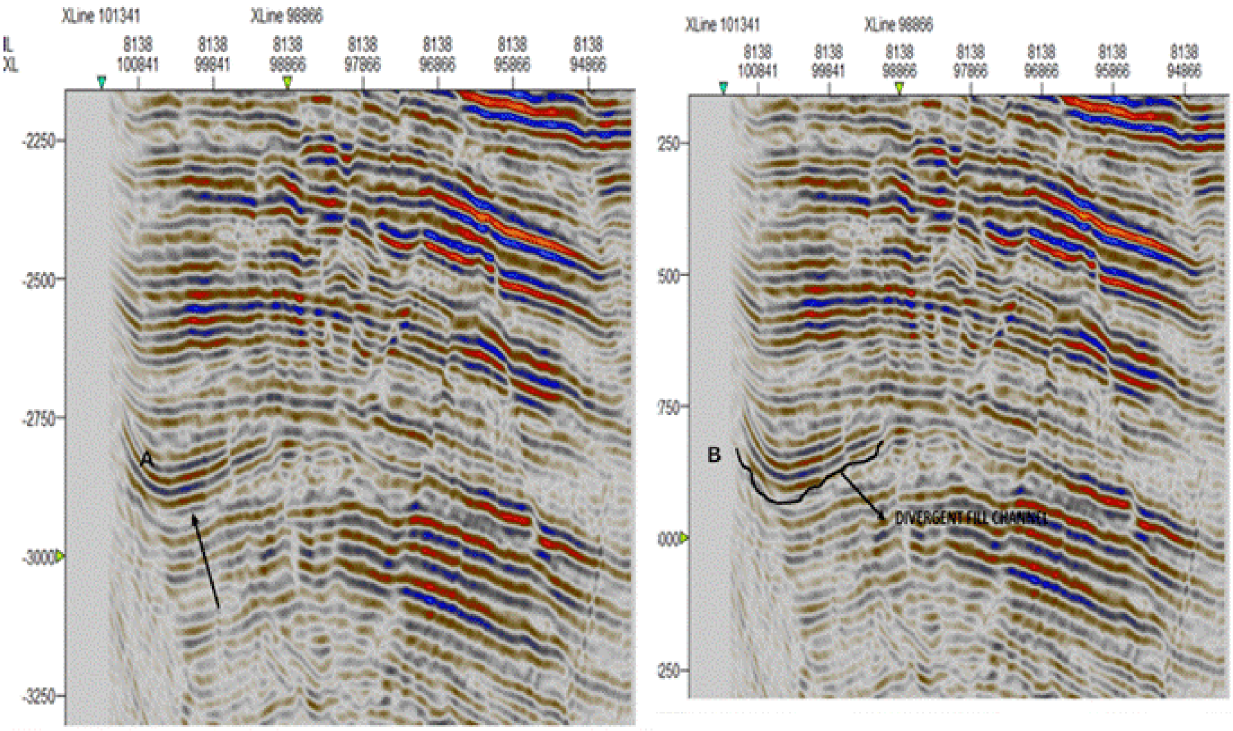


Fig. 9: inline section 8138 on crossline 94866-100841 shows (a) uninterpreted channel and (b) interpreted channel

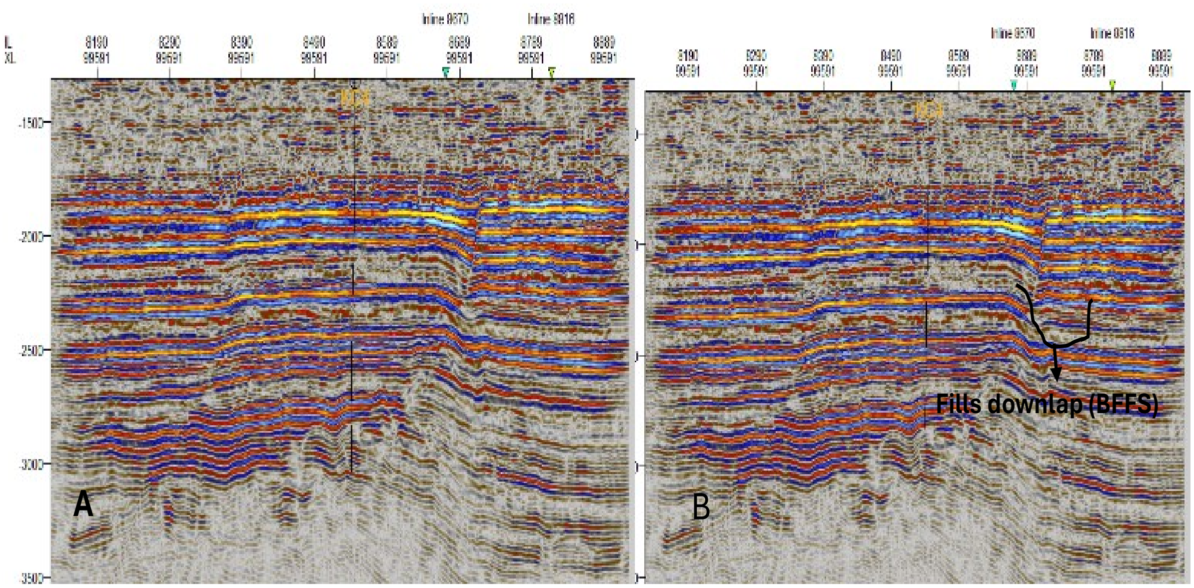


Fig. 10: Inline seismic section 8905 on crossline 93866-103841 showing (a) uninterpreted mounded fill and (b) interpreted mounded fill

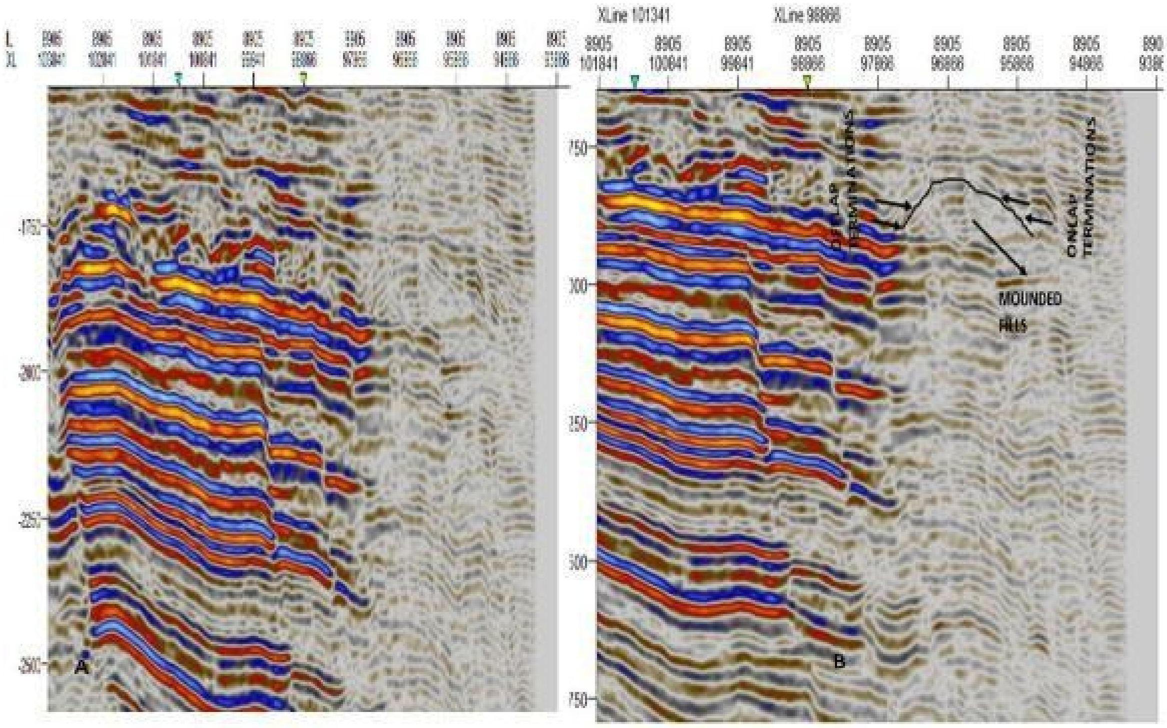


Fig. 11: Inline seismic section 8462-8941 on crossline section 103341 shows (a) uninterpreted channel and (b) interpreted channel (Onlap Fill).

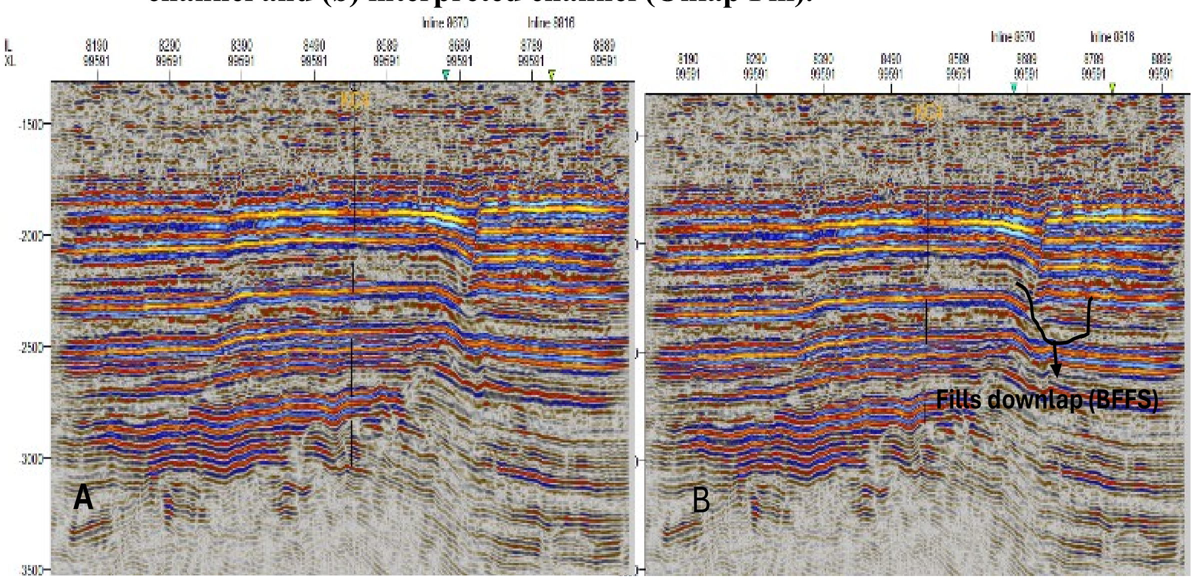


Fig. 12: Inline seismic section 8190-8889 on crossline 99591 showing (a) uninterpreted channel (downlap fills) and (b) interpreted channel (downlap fills)

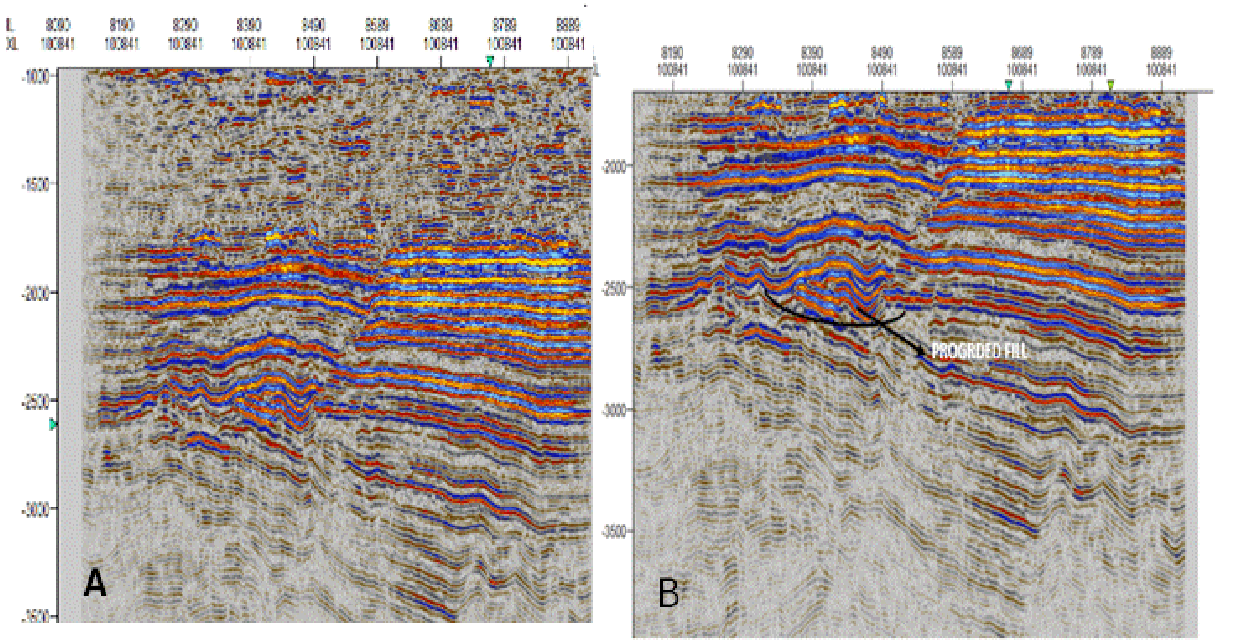
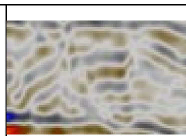
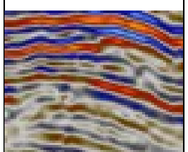
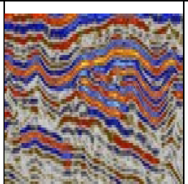


Fig. 13: Inline seismic section 8090-8889 on crossline 100841 showing (a) uninterpreted channel (b) interpreted channel (Prograded Fill)

Table 1: Classification of the channel fill deposit and characteristics in the study area.

Channel fill type	**Example**	**Description**					
		Seismic facies	**reflection configuration**	**reflection continuity**	**reflection amplitude and frequency**	**bounding relationship**	**Environment of Deposition**
I		Oblique semi continuous moderately high amplitude	oblique	Semi continuous	Moderately low amplitude and high frequency	Thinning basinward	Upper slope

II		Mounded , discontinuous and low frequency	Contorted to mounded shape	discontinuous	Low amplitude to high frequency	Onlap, downlap, toplap, and truncation	Basin floor
III		Sub parallel, discontinuous, low amplitude , high frequency	Sub parallel	discontinuous	Low amplitude and high frequency	Onlap and downlap truncation	Inner shelf
IV		Blocky semicontinuous high amplitude	oblique	semicontinuous	medium-high amplitude, high frequency	downlap	Lower slope
V			Parallel to low – angle oblique or sigmoidal	discontinuous	High amplitude and frequency	Strata downdip at a higher angle by downlap against the lower surface	Shelf margin and prograded slope

3.3 Seismic sequence analysis

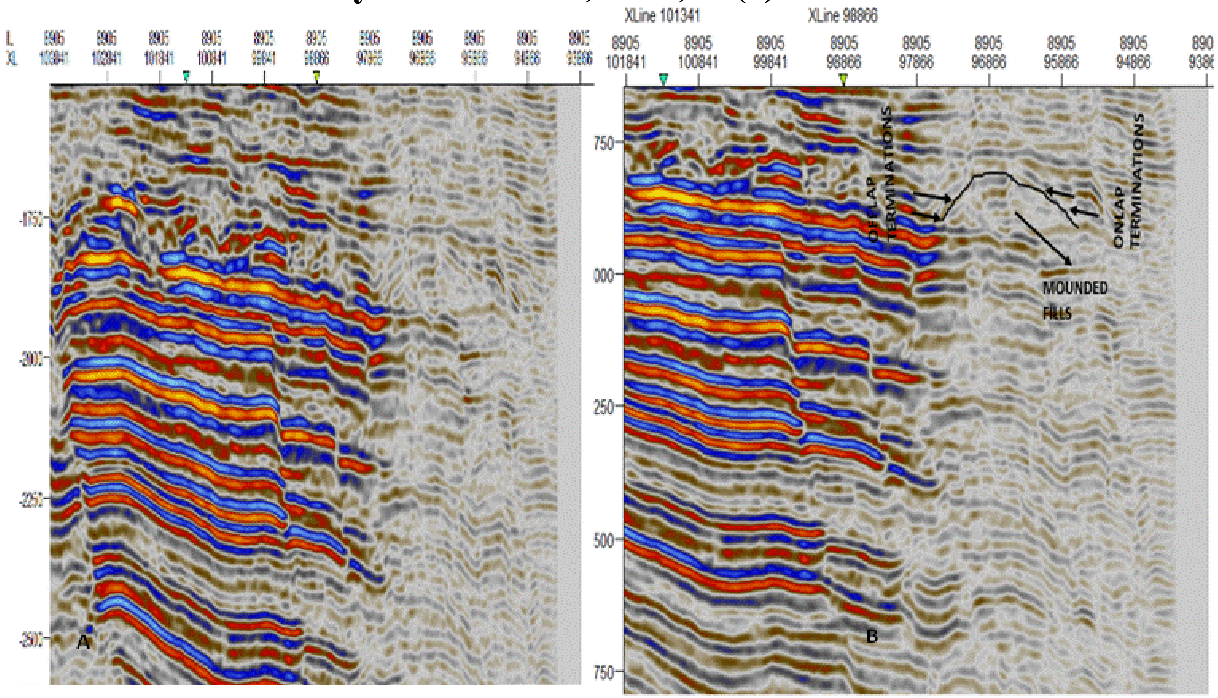
Sequence stratigraphic analysis established the temporal and spatial relationships between depositional sequences, enabling the identification of accommodation-space variations, systems tracts, and potential reservoir intervals associated with relative sea-level fluctuations.

SQ1: seismic sequence 1 is bounded below by sequence boundary 1 (SB1), which is an erosional surface marked by truncation of underlying reflections and onlap of overlying reflections. It overlies the maximum flooding surface 1 (MFS1) and is directly below the base of reservoir C. It is found in Wells KC1, KC2 and KC3 at the depth ranges from 11441.58ft to 11769.65ft with the associated maximum flooding surface below it that varies from 11776.90ft to 11974.41ft in depth (Figures. 14 and 15). The variation in thickness that is thinner in the northwestern and central parts is associated with the uplifted structure below the sequence (i.e. SB1) and the consequent growth of strata on the downthrown side of the major regional fault (F1) as shown in (Figure 16). The Maximum Flooding Surface (MFS1) subsequently divides the sequence in into Low system tract (LST) and High system tract (HST) as demonstrated in (Figure. 14). The thinning of SQ1 across uplifted structural highs reflects reduced accommodation space during deposition, whereas thickening towards the downthrown fault blocks indicates syn-depositional growth fault activity. These observations demonstrate the strong structural control exerted on sediment accumulation within the field.

SQ2: seismic sequence 2 is superimposed conformably by seismic sequence 1.it is bounded below and above by sequence boundary 1 (SB1) and sequence boundary 3 (SB3) respectively with an intrasequence maximum flooding surface 2 (MFS2). It is found in KC1, KC2 and KC3) (Figure. 17) at depths between 10727.09ft and 11096.77ft. The sequence is thicker in the northern and southern parts of the field than the central part and is subdivided into Low system tract (LST) and High system tract (HST). The observed thickness variations suggest localized differential subsidence during deposition. Such variations may influence reservoir continuity, therefore constitute important considerations during reservoir modelling, and field development.

SQ3: seismic sequence 3 overlies seismic sequence 2, and is bounded below by sequence boundary 2 (SB2) and above by sequence boundary 4 (SB4) with an intra-sequence maximum flooding surface 3 (MFS3). It occurs in Wells KC1 and KC2 (Figure 14a), at depths between 10487.56 and 9218.02, 10791.09 and9759.53ft, respectively. The thickness reaches its maximum at the central part of the field with a corresponding gradual decrease in thickness in the southeastern part of the field. The Maximum flooding surface further subdivides the sequence into Low system track and high system track (Figure 16). The central thickening of SQ3 indicates increased sediment accommodation, probably associated with active fault-controlled subsidence. Reservoir intervals developed within these thicker successions may possess greater storage capacity than equivalent intervals elsewhere in the field.

SQ4: SQ4 is overtly overlain by seismic sequence 5 (SQ5), and is bounded above and below by sequence boundary 5(SB5) and sequence boundary 4(SB4) respectively. The intrasequence maximum flooding surface 4 (MFS4) divides the sequence into Low system track (LST) and High system track (HST) (Figure 16). It occurs in Wells KC1 and KC2 (Fig. 12a), at depths between 9759.53 and 9218.02ft. The thickness differs but largely increases in the northeast – southeast direction where it attains its maximum thickness (Figure 15). The progressive southeastward thickening reflects continued basinward sediment progradation and increasing accommodation space, conditions that favour the preservation of laterally extensive reservoir unit



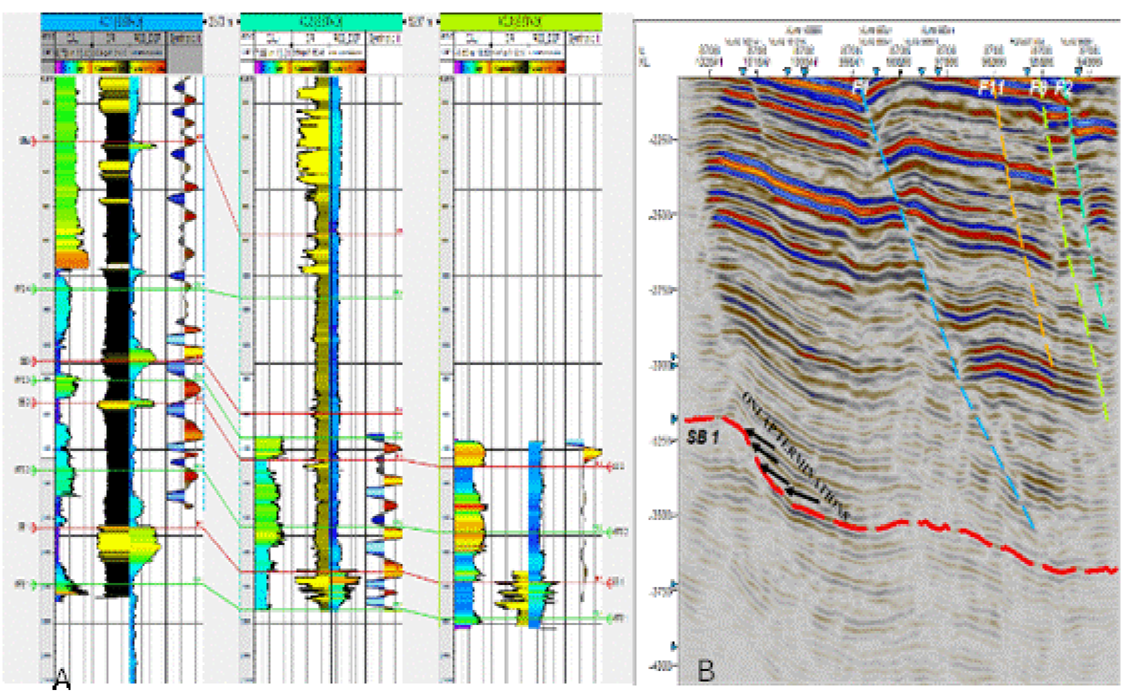


Fig 14: (a) the sequence boundary (SB), Maximum flooding surfaces (MFS) and their correlation across the Wells KC1, KC2, KC3 (b) Inline sections 8708 showing some of the identified faults (F) and onlap terminations used to identify SB1.

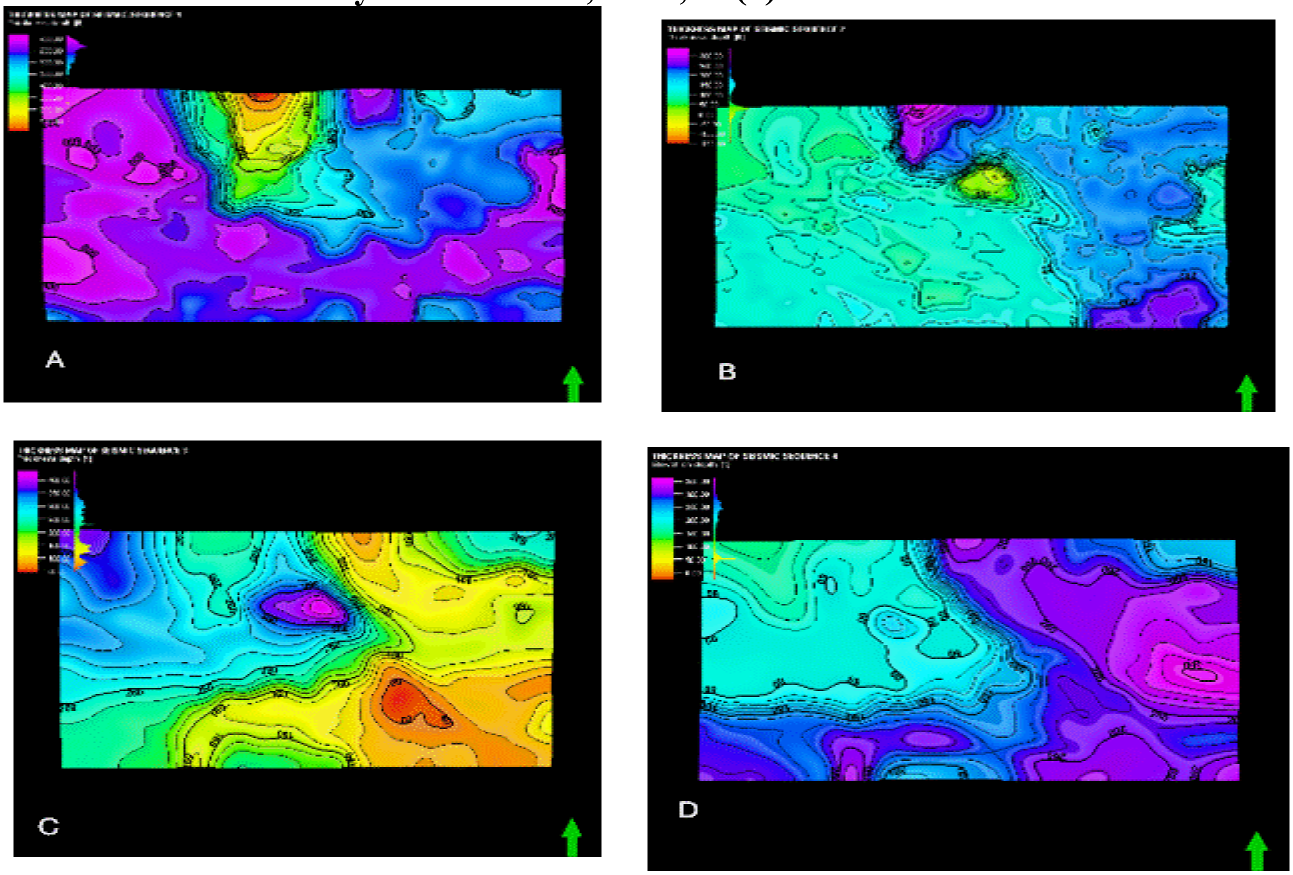


Fig. 15: Thickness maps of (A) seismic sequence 1 (SQ1), (B) seismic sequence 2 (SQ2), (C) seismic sequence 3 (SQ3), and (D) seismic sequence 4 (SQ4)

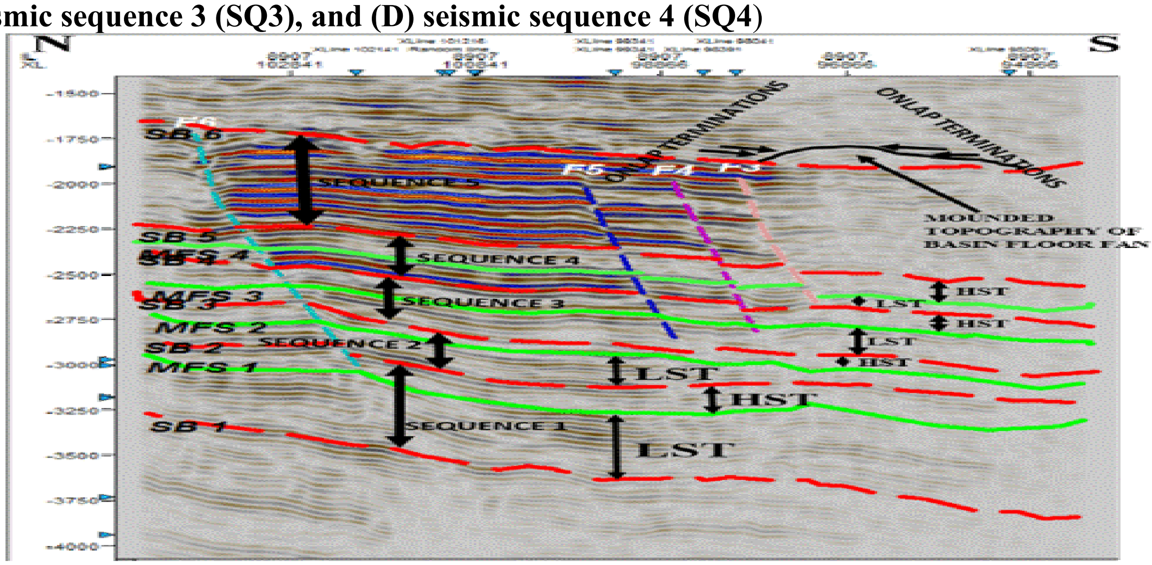


Fig. 16: Inline section 8907 showing some of the identified faults (F), stratigraphic surfaces (SB and MFS), interpreted seismic sequences, system tracts (HST-highstand system tract, LST-lowstand system tract) and basin floor fan complex on SB6.

3.4.Seismic Facies Analysis and Environment of Deposition

Seismic facies interpretation provided additional constraints on depositional environments by integrating reflection geometry with well-log responses. The interpreted facies reveal systematic variations in sedimentary processes, lithology, and depositional energy across successive stratigraphic sequences.

3.4.1 Below sequence boundary 1 (SB1)

The seismic facies below this boundary are consist of two basic seismic facies units classified as SFA and SFB (Figure 17 and Table 2). SFA is characterized by chaotic discontinuous reflection with moderate to high amplitude and high frequency and is interpreted to be dominantly shale, while SFB is characterized by parallel to discontinuous reflection, moderate to high amplitude, moderate to low frequency. This facies unite is interpreted to be an intercalation of sand and shale. They are the products of mixed energy environment and are deposited on a shelf to deep marine environment but has been interrupted owing to the over pressuring of the shale. Figure 17a shows the distribution of SFA and SFB. The predominance of shale-rich seismic facies beneath SB1 suggests deposition under relatively deep-water marine conditions characterized by reduced sediment energy. Such intervals are expected to possess poor reservoir quality but may constitute effective regional seals for overlying hydrocarbon reservoirs

3,4,2 Seismic sequence 1 (SQ1)

Two distinctive seismic facies units categorize SQ1 (SFC and SFD) (Figure 17b and Table 2). SFC consist of continuous to wavy parallel reflections, with high amplitude moderate to low frequency. The Gamma ray log readings from Well KC1 shows that this facies unit is dominantly shale, while SFD contains hummocky clinoform, discontinuous reflections with low amplitude and low frequency deposited in a shelf environment in a mixed energy setting. Gamma ray log values from Well 1 (KC1), which infiltrate to this depth, reads both high indicating sand segments. Figure 17b, shows the distribution of SFC and SFD below and above maximum flooding surface 1 (MFS1) respectively. The coexistence of shale-rich and sandstone-rich facies within SQ1 indicates fluctuating depositional energy associated with shoreline migration during changing relative sea level. These variations contribute significantly to reservoir heterogeneity within the field.

3.4.3 Seismic sequence 2 (SQ2)

SQ2 is characterized by subparallel to moderately continuous reflections, low amplitude and moderate to low frequency facies unit (SFE). The reading from the Gamma ray log revealed that the facies are sand and shale dominant deposited in middle to inner shelf environment with variable energy (Figure 17c). The interbedding of sandstone and shale suggests alternating episodes of sediment influx and marine flooding, producing moderate reservoir quality with localized high-quality sandstone bodies.

3.4.4 Seismic sequence 3 (SQ3)

SQ3 is characterized by parallel to continuous, low to high amplitude and moderate to low frequency reflections of seismic facies G (SFG). The Gamma ray signature from Well 1(KC1) revealed that the facies is made up of sand and shale intercalations reflecting low energy, inner shelf to slope deposits. Figure 17d shows the distribution of SFG. The interpreted inner shelf to slope deposits indicate gradual basinward sediment transport under relatively low-energy conditions. Such environments commonly generate laterally continuous reservoir sands interbedded with marine sealing shales.

3.4.5 Seismic sequence 4 (SQ4

SQ4 consist of one seismic facies unit (SFH) (Figure 18a and Table 2) which comprises of parallel to oblique tangential reflection configuration with a high to very high amplitude and moderate to high frequency. The Gamma ray interpretation of the facies confirmed it to be dominantly shale and is suspected of low energy, slope to basin floor environment of deposition. Figure 18a shows the distribution of SFH. The dominance of shale-rich facies within SQ4 suggests deposition below storm wave base where suspended sediment settled under quiet marine conditions, resulting in effective sealing lithologies rather than productive reservoirs

3.4.6 Seismic sequence 5 (SQ5)

SQ6 seismic facies categorized as SFI comprises subparallel reflection configuration, low to very low amplitude, low to very low frequency. The log signature on the Gamma ray revealed sand and shale deposits due to variable energy and considered to be deposited in inner to slope marine environment (Figure 18b). The variable lithology within SQ5 reflects repeated changes in depositional energy and shoreline position during basin evolution, leading to heterogeneous reservoir quality across the sequence.

The seismic facies identified throughout the study area, together with their reflection characteristics, inferred lithologies, and depositional environments, are summarized in Table 2. The systematic relationship between seismic response and depositional setting provides a robust framework for predicting reservoir distribution within the Ekwai Field.

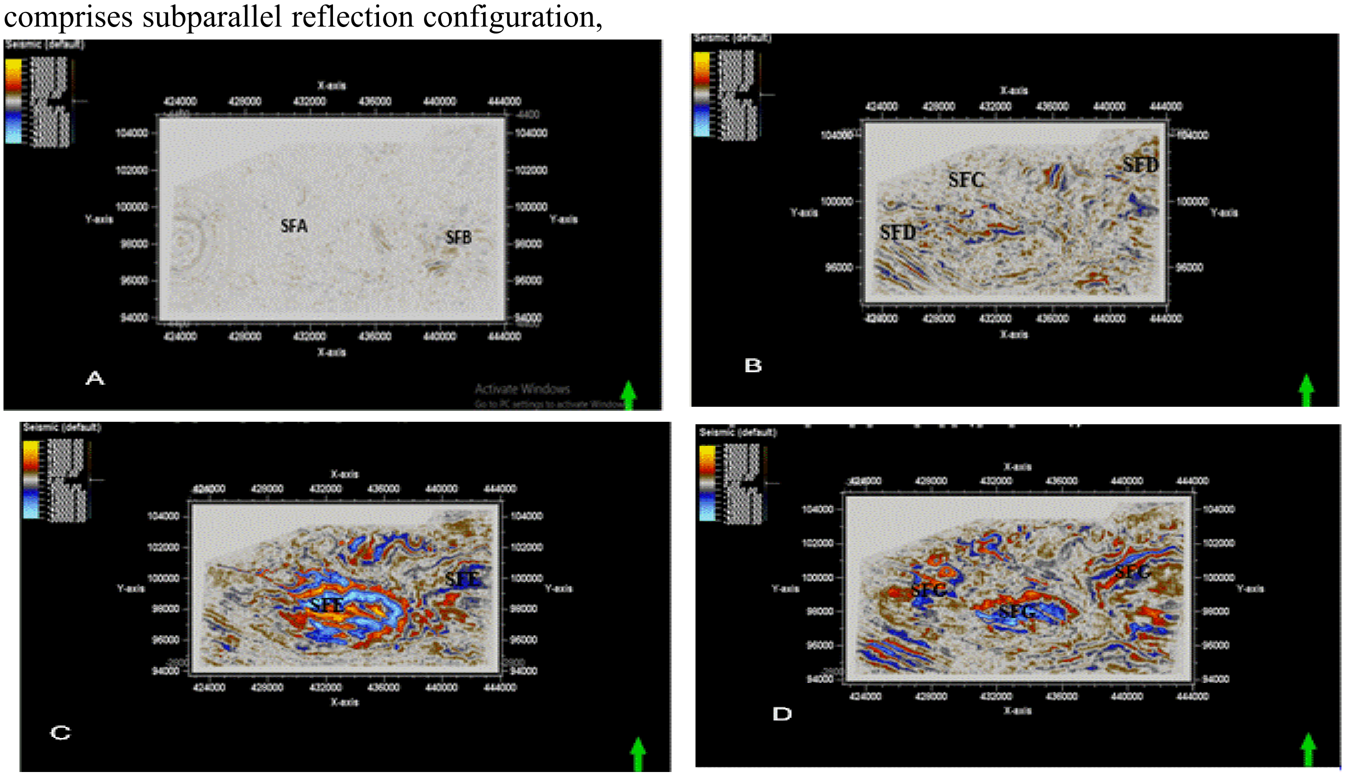


Fig. 17: Seismic time – slice maps at (a) -4380 ms (TWT), (b) -3148 ms (TWT), (c) -2764 ms (TWT), (d) -2684 ms (TW), showing the distribution of seismic facies units (SFA, SFB, SFC, SFD, SFE, SFF, SFG), below SQ1 and within SQ1 – SQ5 and MFS1 – MFS4 in the seismic section

3.5 Implications for Hydrocarbon Exploration

The integrated interpretation demonstrates that hydrocarbon prospectivity within the Ekwai Field is controlled by the interaction of depositional architecture, sequence stratigraphy, and structural evolution. Channel Types II, III, and IV constitute the prospective reservoir targets because of their coarse-grained lithology, favourable seismic attributes, and association with basin-floor fan and prograding depositional systems. Conversely, Types I and V are dominated by fine-grained sediments and therefore exhibit limited reservoir potential. The sequence stratigraphic framework further reveals that reservoir distribution is strongly influenced by relative sea-level fluctuations and growth-fault-controlled accommodation space. These findings reduce exploration uncertainty and provide a reliable geological framework for future drilling and reservoir development within the eastern Niger Delta.

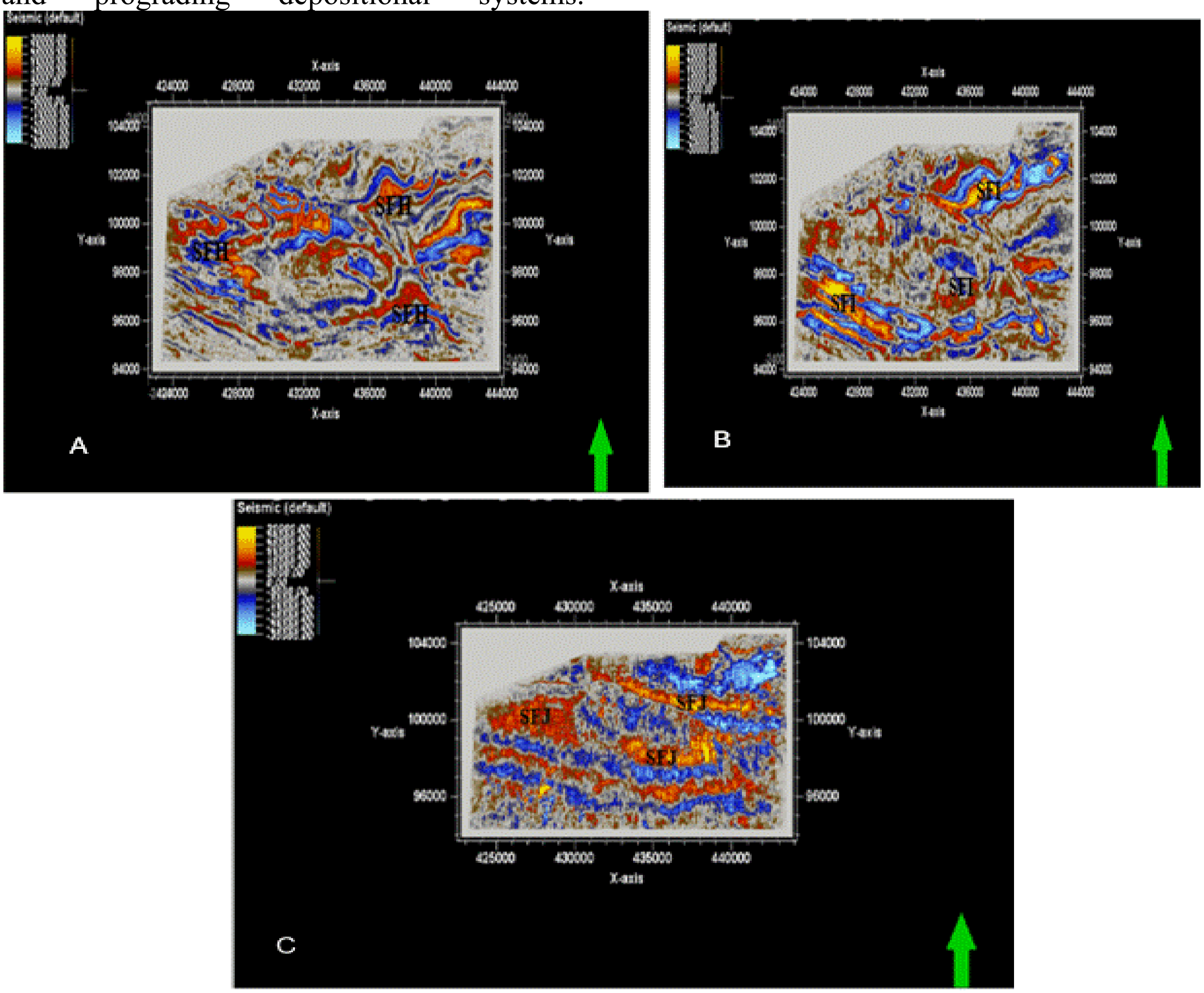
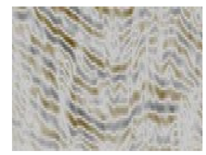
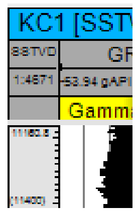
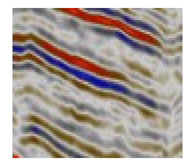
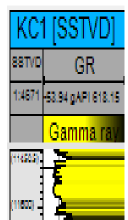
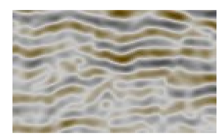
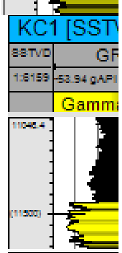
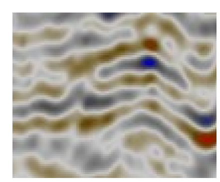
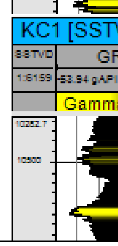
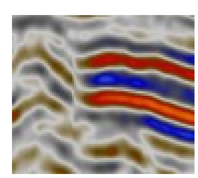
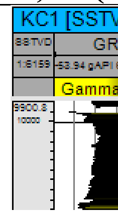
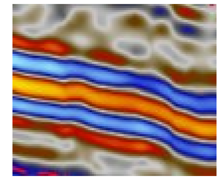
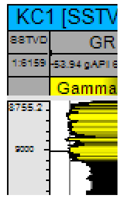
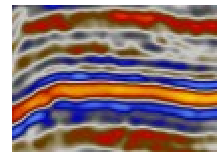
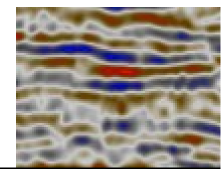


Fig. 18: Seismic time – slice maps at (A) -2920ms (TWT), (B) -2836 ms (TWT), (C) -1628 ms (TWT), showing the distribution of seismic facies units (SFH, SFI, and SFJ), within SQ4 – SQ5 and above SQ6 in the seismic section.

Table 2: Seismic facies characteristics and the inferred depositional environment of the field of study. The yellow colour on gamma ray log example indicate sand while the black colour indicate shales.

Seismic sequence (sq)	SFU	RCC	RAF	GRL	LI	DEE	Seismic example
Below sequence boundary 1 (SQ 1)	SFA	Chaotic, discontinuous	Moderate to high amplitude		Shale	Mixed energy, shelf to deep marine	
	SFB	Parallel to discontinuous reflection	Moderate to high amplitude, Moderate to low frequency		Sand and shale		
SQ 1	SFC	Continuous to wavy parallel reflection	High amplitude, moderate to low frequency		Dominantly Shale	Mixed energy, Shelf	
	SFD	Hummocky clinoform, discontinuous	Low amplitude, Low frequency		Sand		
SQ 2	SFE	Subparallel, moderately continuous	Low amplitude, moderate to low frequency		Dominantly sand and shale	Variable energy, middle to inner shelf	
SQ 3	SFG	Parallel discontinuous	Low to high amplitude, moderate to low frequency		Sand and shale	Low Energy, Inner Shelf to Slope	

SQ 4	SFH	Parallel to oblique tangential	High to very high amplitude, moderate to high frequency		Dominantly Shale	Low energy, Slope to basin floor	
SQ 5	SF I	Subparallel	Low to very low amplitude, low to very low frequency		Sand and shale	Variable energy, Inner to slope	
Above SQ 6	SFJ	Parallel discontinuous, Chaotic	Moderate to high amplitude, low to very low frequency		Sand and shale	Variable energy	

SFU= Seismic facies unit (sf), RCC = RAF = Reflected amplitude and frequency, GRL = Gamma ray log example, LI = Lithology interpretation, DEE = Depositional energy and environment

4.0 Conclusion

This study successfully integrated three-dimensional (3-D) seismic data, wireline logs, and sequence stratigraphic analysis to characterize the stratigraphic trapping framework, depositional architecture, and seismic facies of the Ekwai Field in the eastern Niger Delta. The interpretation revealed that hydrocarbon accumulation is controlled by a combination of facies changes, depositional pinch-outs, and five distinct distributary channel-fill architectures that reflect varying depositional environments and reservoir characteristics. Among the identified channel systems, Types II, III, and IV exhibit favourable seismic attributes and depositional characteristics indicative of coarse-grained reservoir sands with high hydrocarbon prospectivity, whereas Types I and V are dominated by finer-grained sediments and are considered less prospective.

Sequence stratigraphic interpretation established a robust chronostratigraphic framework comprising five sequence boundaries (SB1–SB5) and four maximum flooding surfaces (MFS1–MFS4), which subdivide the sedimentary succession into genetically related depositional sequences and systems tracts. Variations in sequence thickness, reflection geometry, and internal seismic configuration indicate that sediment distribution within the field was strongly influenced by relative sea-level fluctuations, syn-depositional fault activity, and accommodation-space development.

Seismic facies analysis identified distinct facies assemblages (SFA–SFJ), each characterized by unique reflection configurations, amplitudes, frequencies, and continuity patterns that enabled the interpretation of lithological variations, depositional energy conditions, and sedimentary environments. The integration of seismic facies, sequence stratigraphy, and structural interpretation significantly improved the delineation of reservoir distribution and stratigraphic trapping mechanisms within the field.

Overall, the study demonstrates that an integrated seismic stratigraphic approach provides a reliable framework for identifying subtle stratigraphic traps, reducing exploration uncertainty, and improving reservoir characterization. The geological model developed from this investigation provides valuable guidance for future hydrocarbon exploration and field development in the Ekwai Field and other geologically analogous areas of the Niger Delta Basin.

The principal contribution of this study lies in demonstrating, at the scale of an individual producing field, that the integration of 3-D seismic interpretation, sequence stratigraphy, and seismic facies analysis constitutes a robust and transferable framework for identifying subtle stratigraphic traps and reducing exploration risk in mature deltaic basins such as the Niger Delta. By resolving the channel-fill architecture and stratigraphic trapping elements of the Ekwai Field, a level of detail not captured in previous regional-scale studies, this work provides a replicable workflow that operators can apply to other structurally mature fields to identify bypassed, stratigraphically trapped hydrocarbon volumes and thereby extend field life.

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Declaration

Competing Interests

The authors declared no competing interest

Ethical Consideration

Not applicable

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Authorship contribution statement

E.P.A. conceived the study, conducted seismic interpretation, data analysis, and prepared the initial manuscript. D.A.O. supervised the research and reviewed the manuscript. S.I.U. contributed to sequence stratigraphic and facies analyses. M.E.O. validated the results and assisted with interpretation. C.E.M. contributed to data processing, visualization, manuscript editing, and approved the final version.

Availability of data and material

All data used in this manuscript are original except those duly acknowledged and cited by the author.