GLOBAL JOURNAL OF GEOLOGICAL SCIENCES VOL 8, NO. 1, 2010: 43-56

THE APPLICATION OF SEISMIC-LOG SEQUENCE STRATIGRAPHY IN MAPPING STRATIGRAPHIC TRAPS AND RESERVOIRS' FACIES IN AFAM CHANNEL AREA, NIGER DELTA

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(Received 17, March 2009; Revision Accepted 23, September 2009)

ABSTRACT

The concept of seismic-log sequence stratigraphy was used in mapping stratigraphic traps and reservoirs' facies in Afam Channel area, Niger Delta, for the purpose of prospect re-evaluation and improving production. The data set consists of 3-D seismic data and conventional well logs, which were interpreted iteratively using workstation based interpretation technique. The well logs were converted from depth domain to time domain and subsequently superimposed on the seismic time sections at oil wells' locations. Areal mapping of the delineated reservoirs' facies based on composite well logs display, deduced trapping mechanisms and inferred depositional environments were then carried out on the seismic sections using consistency of the associated seismic reflection characters. The seismic sections and well logs were subsequently sub-divided into sequence units, systems tracts and facies units.
The Afam Channel fill sequence is sub-divisible into lowstand, transgressive, and highstand system tracts with a major condensed section separating the transgressive from the highstand system tracts while a "type 1 sequence boundary separates it from the pre-channel sequence. Structural entrapments comprise one-way and two-way closures against faults that most often bound structural highs. Stratigraphic traps range from lithofacies thinning up dip, onlapping of pre-channel sequence, lateral facies change especially across channels edges and combination traps. The hydrocarbon reservoirs' facies are interbedded within the paralic sequence of the lower transgressive through to the lowstand systems tracts and the pre-channel sequence within a depth range of about 6000ftss to 11800ftss (1829m to 3597m). Reservoirs geometries range from sheet, sheet drape, lenses, wedge and mounds. The hydrocarbon reservoirs' facies are multi-stacked, thereby making the prolific level of each oil well being dependent on how many it intercepted optimally.

KEY WORDS: Declining Production Prospect Re-evaluation Seismic-Log-Sequence Stratigraphy Hydrocarbon Reservoirs' Facies Exploitation Strategy

INTRODUCTION

New discoveries outside renowned oil provinces globally are very few. The current trends are efforts geared at exploring for stratigraphically entrapped petroleum and optimizing recovery from old and new fields through accurate deduction of geologic setting, reservoirs characterization, geometry and interconnectivity for the purpose of field development, projecting production and prospects re-evaluation. The Afam Channel area is a matured prospect consisting of over seventy oil wells that were drilled between 1956 and 1991 and distributed in about twelve independent oil fields. Decline in production or outright marginal production is being experienced in some of these oil wells, which necessitated a 3-D seismic survey in the late 1990s. Amongst the objectives were to redefine the petroleum entrapments mechanisms, map reservoirs' facies and consequently re-evaluating the prospect. Information on geologic parameters such as geological setting, depositional conditions, facies prone type, reservoirs' facies geometries and distribution are vital to both field development and designing production strategies.

Seismic-log sequence stratigraphic analysis provides a basis for elucidating those geologic factors that directly influence the areal distribution of reservoirs facies, geometries, qualities and eventually the establishment of petroleum trapping mechanisms in a prospect area. The approach employs imaging of the subsurface stratigraphy as encoded on the seismic time sections and well logs signatures. The seismic stratigraphic approach has been applied in some matured oil fields in the Niger Delta wherein the plays are more of stratigraphically entrapped petroleum than structural and in structurally complex prospects with the prime objective of improving production (Ladipo, 1992, Bowen et al., 1994, Krusi and Idiagbor, 1994, Overell and Nwachukwu, 1995, Adejobi and Olayinka, 1997 and Tegbe and Akaegbobi, 2000). The underlying principle is that the gross stacking and geometry of adjacent facies units mostly determine the overall reflection characters at each locality. Widess (1973), stated that separate reflections from the top and bottom of a unit can be identified down to a critical thickness of about 1/8λ of the wavelet central frequency. Above the critical thickness, the time thickness gives an estimate of the bed

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thickness, while below the critical thickness, the time thickness is constant and information on bedding thickness is expressed in the amplitude of the event. Thus lithologic units that are thick enough or have large enough acoustic impedance contrast at their margins can be easily identified and mapped and becomes increasingly seismically invisible as the units thin out or the acoustic impedance contrast reduces. Neidel and Poggliogliolmi (1977), stated that subtle changes in amplitude and waveform can be directly correlated to variations in geologic properties such as lithology, bed thickness, fluid content and beds spacing. Log sequence analysis enables a delineation of a well section into lithologic units, identify hydrocarbon reservoirs' facies, deduce facies' depositional environments and subdivision into sequence units, systems tracts and facies units. The conversion of well logs from depth domain to time domain enables their superimposition on seismic time sections and the mapping of hydrocarbon reservoirs' facies on seismic time sections based on areal consistency of reflection characters. Lateral changes in waveforms are assumed due to lithofacies changes, fluid type or lithofacies boundaries, which do culminate to areal changes in acoustic impedance. This approach provides the basis of adjudging hydrocarbon reservoirs' facies as optimally intercepted, non optimally intercepted or outrightly bypassed at each oil well location. Thus based on the outcome, strategies for improved production can be adduced. Additionally, by integrating the results derivable from seismic-log sequence stratigraphy with other data sets such as core samples and biostratigraphic data, a complete elucidation of the depositional sequence and history of the basin is achievable. The present study entails structural, stratigraphic and log sequence analyses of 3-D seismic data and well logs acquired in Afam Channel area for the purpose of mapping stratigraphic traps and reservoirs' facies for the purpose of prospect re-evaluation and improving production traps in the Afam Channel area, Niger Delta.

GEOLOGICAL SETTING

Afam Channel area is an incised paleo-channeling system located within the Coastal Swamp Depobelt, onshore Eastern Niger Delta (Figure 1). It was incised on the outbuilding delta front during sea-level lowstand and backfilled in the succeeding marine transgression in the Miocene. Similar generic paleochannels in Eastern Niger Delta include Agbada, Buguma, Kwa Iboe and Soku Channels respectively (Burke, 1972, Murat, 1972, Evamy et al., (1978), Gordon and Omatsola, 1987). According to Burke (1972), Gordon and Omatsola (1987), they are estuaries with offshore submarine canyons while Murat, (1972), stated that they are river gullies filled and buried by transgressive clays. Evamy et al., (1978), stated that five of the Eastern Niger Delta gullies were all formed during the Miocene as erosional features via which continental sediments were transported by fluvial systems and deposited in deep sea floor during eustatic sea level lowstand. The succeeding marine transgression led to the deposition of mainly a paralic sequence in Afam Channel area that is capped with thick clays (Afam Clay Member). The Afam Channel backfilled sequence is underlain by the paralic Agbada Formation deposited in the prograding delta front. The Akata Formation directly underlies the Agbada Formation. It consists mainly marine shales (prodelta shales) with minor associated sandstones inferred lowstand turbidite fans. The Benin Formation directly overlies the channel fill deposits. It is a continental lithofacies (delta plain facies), consisting mainly continental sands and gravels with thin clay lenses. The Niger Delta lithostratigraphic units are strongly diachroneous. The age of the Akata Formation ranges from Palaeocene to Recent (proximal to distal), the Agbada Formation from Eocene to Recent and Benin Formation from Oligocene to Recent.

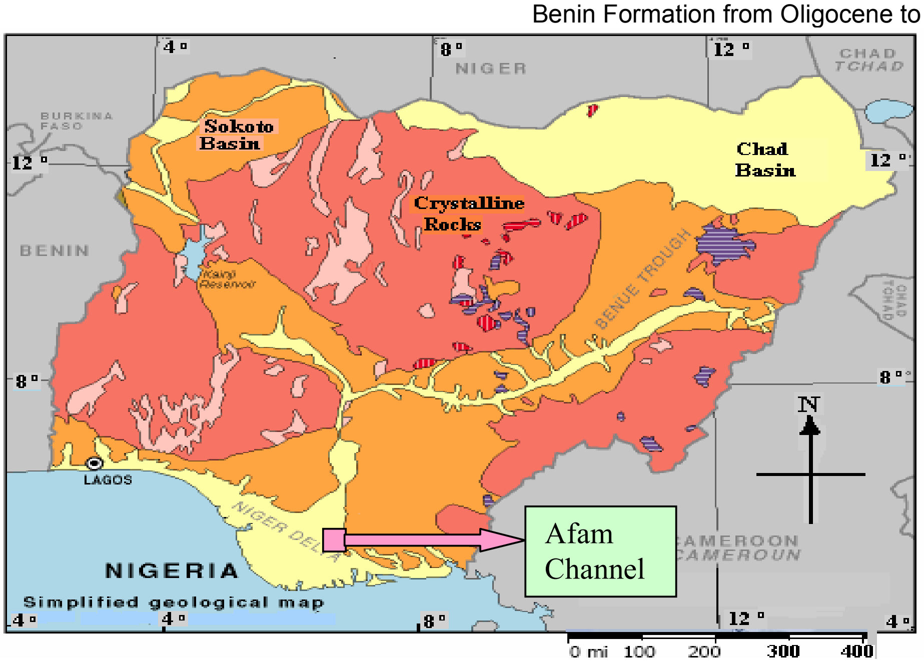


Fig. 1: Simplified Geological Map of Nigeria showing the location of Afam Channel area, Niger Delta.

METHODOLOGY

The data sets consist of migrated 3-D seismic data and conventional well logs that were interpreted adopting iterative workstation interpretation technique using the Kingdom Suite Version 7.6 software. Lithologic units and hydrocarbon reservoirs' facies were identified and delineated on composite logs display while intra-field and inter-fields lithostratigraphic depth sections were produced by inter-wells' correlation of lithofacies units. Environments of deposition of the respective lithofacies units were inferred based on their logs motifs (SP, GR and Rt). Synthetic seismograms were generated for each oil well using velocity information derived from sonic log and/or computed using Faust resistivity-velocity coefficient. Density information was derived from density logs and where not available, constant values ranging from 2.35gcm^{-3} to 2.65gcm^{-3} were used. The input wavelet and trace were extracted at each oil well location, while miniseismic sections were extracted within rectangular grids of twenty traces within each oil well's vicinity. Faults and seismic horizons were picked on the seismic time sections. The two-way traveltimes were used to produce both structural time and depth maps of each seismic horizon picked. These were used to investigate structural trapping mechanisms and their areal disposition. The well logs were converted from depth domain to time domain and superimposed on the field seismic sections at oil wells locations. Seismic sequence and facies analyses were then carried so as to delineate the seismic time sections into sequence units, systems tracts and facies units and infer depositional environments using procedures outlined by Mitchum et al., (1977), Vail et al., (1977), Sangree and Widmier, (1979), Galloway, (1989) and Mitchum et al., (1994). Hydrocarbon reservoirs' facies were mapped on the seismic time sections based on the areal consistency of the seismic reflection characters generated by them.

Structural Style and Traps

The Afam Channel fill exhibits simple structural styles of moderately displaced faulted blocks by normal, reverse and thrust faults that most often flank low-angle-limb folds/structural highs. Six seismic horizons were picked within an average time range of 0.0s to 3.2s of the record length (5.0s), these are from the base: Yellow, Red, Pink, Green, Gold and Blue Horizons.

Figure 2 presents an interpreted seismic section showing the faulting pattern and the seismic horizons that were picked in the study area. Time and depth maps of the respective seismic horizons indicate that structural trapping mechanisms consist of one-way and two-way closures against faults within the Gold, Green, Pink, Red and Yellow Horizons, however, the structural closures within the Gold horizon are less attractive prospects because of their relatively shallow depths. Tight structural one-way and two-way closures against faults are observable on the time and depth maps of Green, Pink and Red horizons respectively with the structural closures against faults within the Green and Pink horizons constituting about 80% of the structural traps/localities wherein existing oil wells are clustery located. These structural closures center on giant structural highs bounded by faults.

The Green horizon lies within a depth range of 5121ft to 9894ft (1561m to 3016m). Lithologic information deduced from well logs shows that this depth range is mainly made up of a paralic sequence in which the interbedded sandstones constitute the first set of hydrocarbon reservoirs' facies that are encountered downhole in Afam Channel area. Figure 3 is a depth map of Green horizon showing structural closures against faults and the locations of existing oil fields in the Afam Channel area. Majority of the oil wells were drilled based structural interpretation of 2-D seismic time sections. The Pink horizon is encountered in a depth range of 7119ft to 14711ft (2170m to 4485m) and based on lithologic information obtained from well logs, it is predominantly a paralic sequence. Most of the existing oil wells bottom hole depths terminate within it, apparently due to over-pressured zones resulting from underlying shale diapers. The Red horizon lies within a depth range of 9378ft to15755ft (2859m to 4803m) and most of the existing oil wells do not penetrate it except those located against channels edges and in Ajokpori Field where structural folding has resulted in its arching to a relatively shallow depth. Lithologic information from well logs indicates that it is composed of a paralic sequence with thicker shale beds and hence more worrisome in hydrocarbon prospecting.

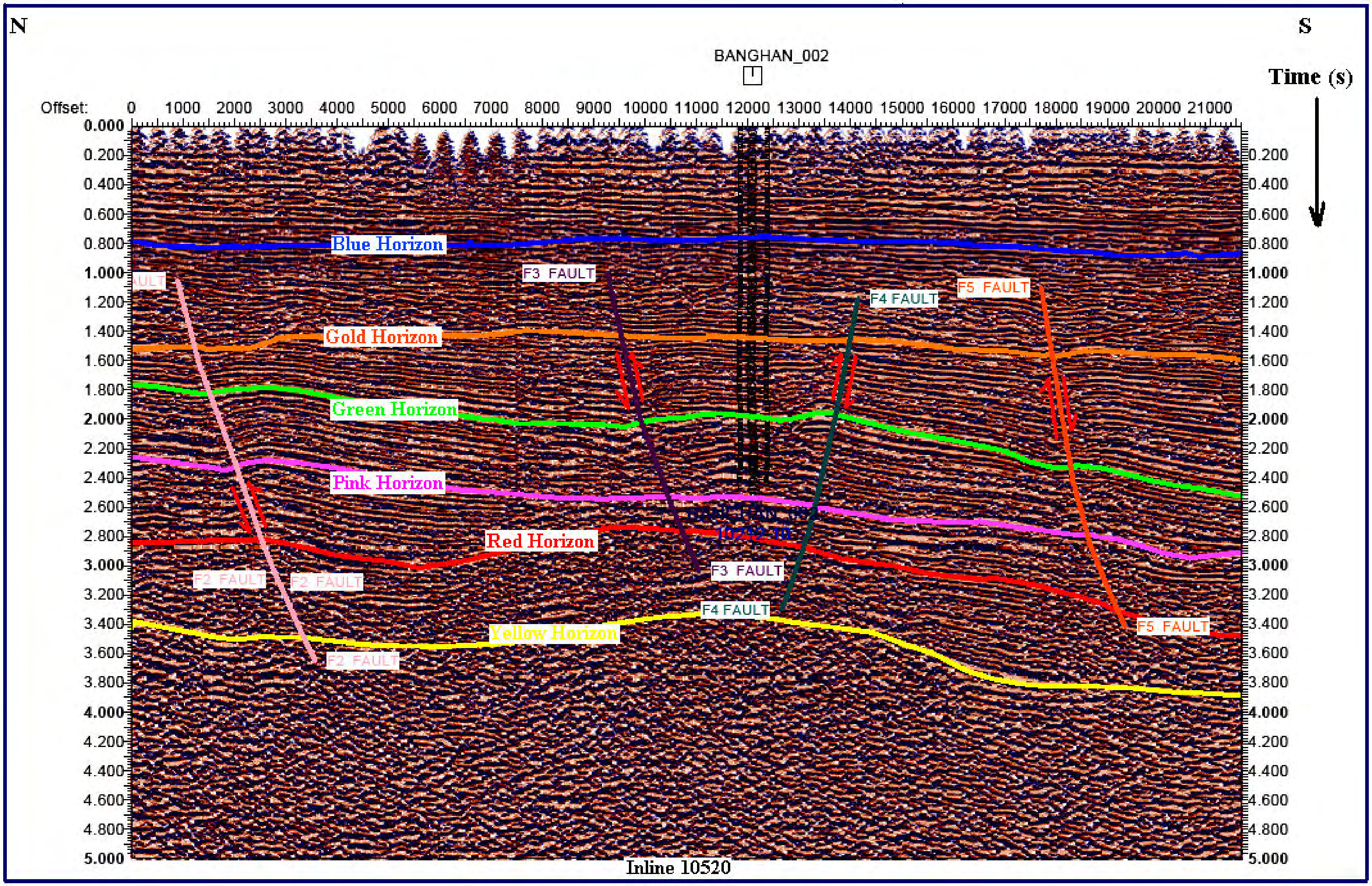


Fig. 2: An Interpreted Seismic Section Showing the Faulting Pattern and Seismic Horizons in Afam Channel Area, Niger Delta.

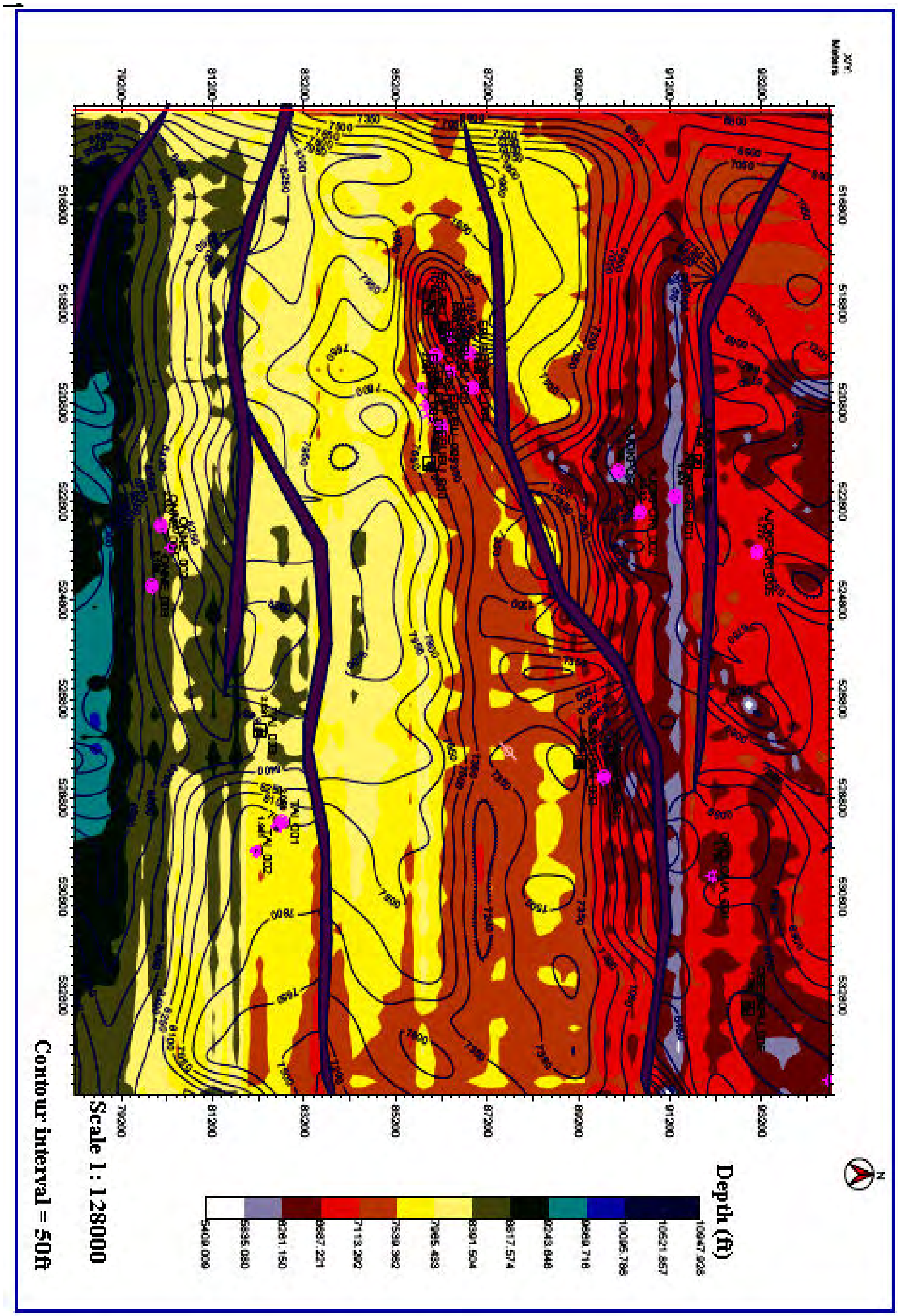


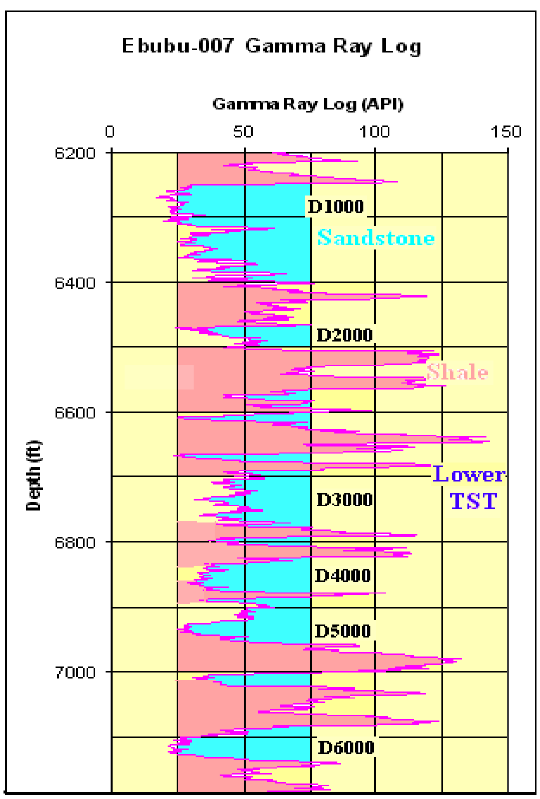
Fig. 3: A Depth Map of Green Horizon In Afam Channel Area, Niger Delta.

The Yellow horizon is encountered within a depth range of 7520ft to17692ft (2292m to 5393m) with less fault blocks and rarely penetrated by oil wells. Consequently, lithologic information about this horizon is very scanty. All potentially viable structural entrapment features have been test drilled. Probable prospects lie in stratigraphic and combination petroleum entrapments.

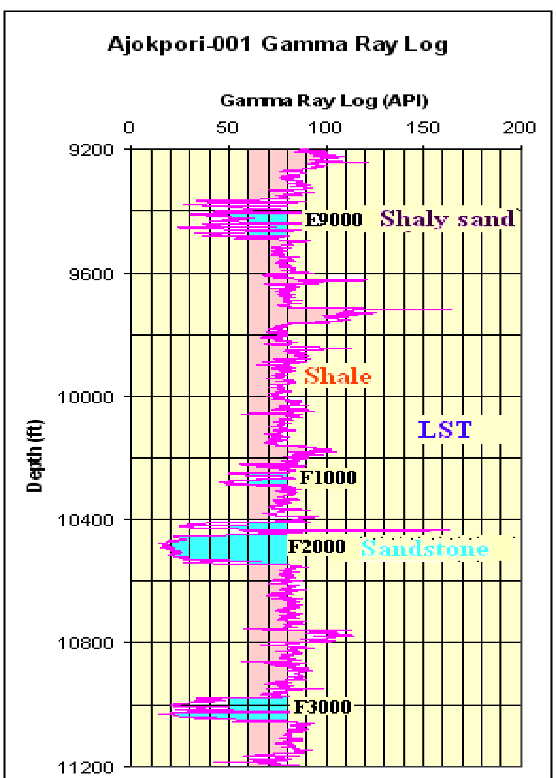
Seismic-Log Sequence Stratigraphy

The Afam Channel back filled sequence is sub-divisible into three systems tracts namely lowstand systems tract (LST), transgressive systems tract (TST) and highstand systems tract (TST) that constitute a type 1 sequence unit. A major condensed section separates the transgressive from the highstand systems tract while the coastal plain deposits cap the sequence to the earth's surface. A "type 1 sequence boundary" separates the overlying lowstand systems tract from the basal pre-channel sequence by onlap reflection termination pattern. It constitutes the erosional surface by fluvial processes during sea – level lowstand. Figure 4 presents well logs signatures of the respective systems tracts and some reservoirs' facies in Afam Channel backfilled sequence. Figures 4a&b are gamma ray log facies shading of the lower transgressive and lowstand systems tracts showing lithofacies units in Ajokpori-001 and Ajokpori- 003 wells respectively while Figure 4c is a composite logs display of Onne-001 well that has been sub-divided into the respective systems tracts and facies units within the Afam Channel area. Figure 5 is an interpreted seismic section showing the seismic signatures of the systems tracts and a time slice at 2.544s (phase) showing the geometry of the paleochanneling system during middle LST in Afam Channel area.

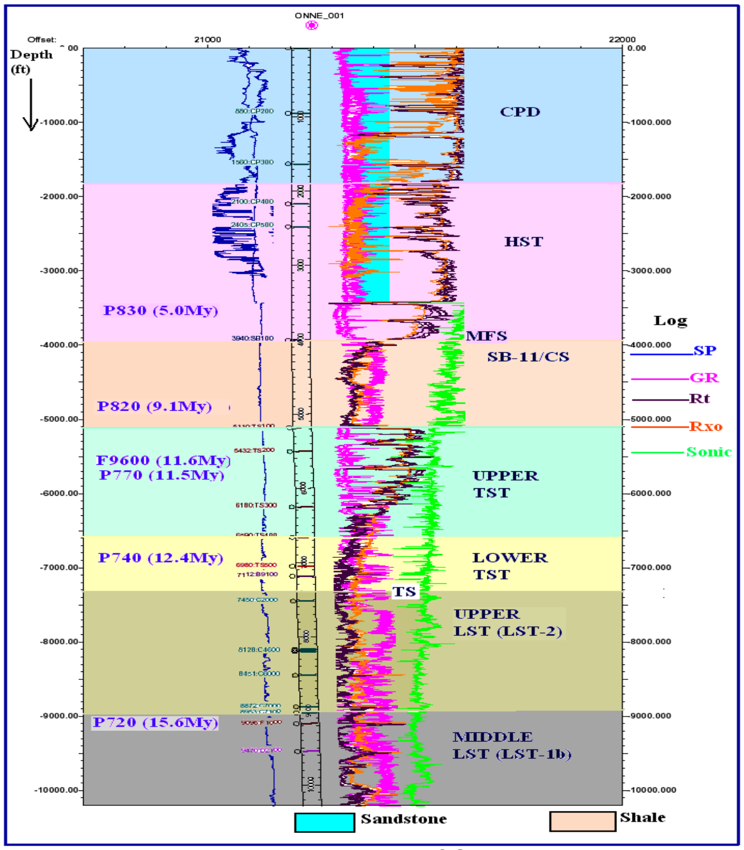
The lowstand systems tract constitutes the basal unit of the channel fill that was deposited in the amalgamated incised channels as the relative sea-level rose. It comprises a paralic sequence that exhibits almost alternating funnel and bell shapes log motifs that are sometimes interspersed by blocky log motif. On seismic sections, it exhibits sub-parallel to parallel, continuous, moderate to high amplitude reflections with its basal part onlapping the pre-channel sequence in a time range of 2.84s to 3.24s (see Figure 5a). This reflection configuration indicates sedimentation over a wide depositional setting in which depositional conditions were quite persistent, which is a re-affirmation of some earlier inferred depositional settings of the Eastern Niger Delta paleochannels as submarine canyons/gullies fills. The depositional system experienced a high frequency of oscillating water depths that ranged from littorial to middle neritic settings thereby producing a paralic sequence that extends from an average depth of 7200ftss to 12000ftss. The reservoir sandstones are straddled in the paralic sequence in which the shale beds are progressively thicker with increasing depth. They constitute the second set of hydrocarbon reservoirs' facies downhole in Afam channel area. This systems tract is sub divisible into early (LST-1a), middle (LST-1b) and late (LST-2). The LST-1a is the basal unit that directly overlies the pre-channel sequence unconformably.



(a) Gamma ray log of lower TST in Ebubu-007



(b) Gamma ray log of LST in Ajokpori-001



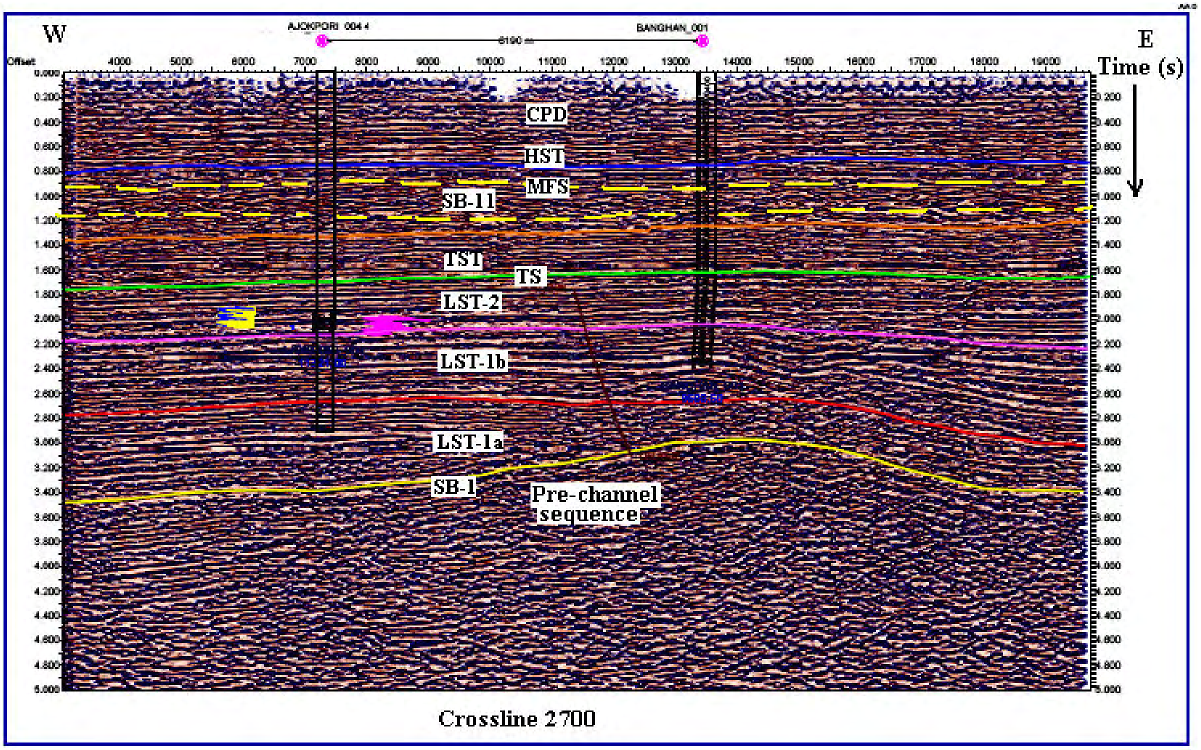
(c) Log sequence analysis of Onne-001 well.

Fig. 4: Well logs showing the respective systems tracts and some reservoirs' facies in Afam Channel area, Niger Delta. (a) A gamma ray log facies shading of lower TST, (b) gamma ray log facies shading of middle LST and (c) Log sequence analysis of Onne-001 well.

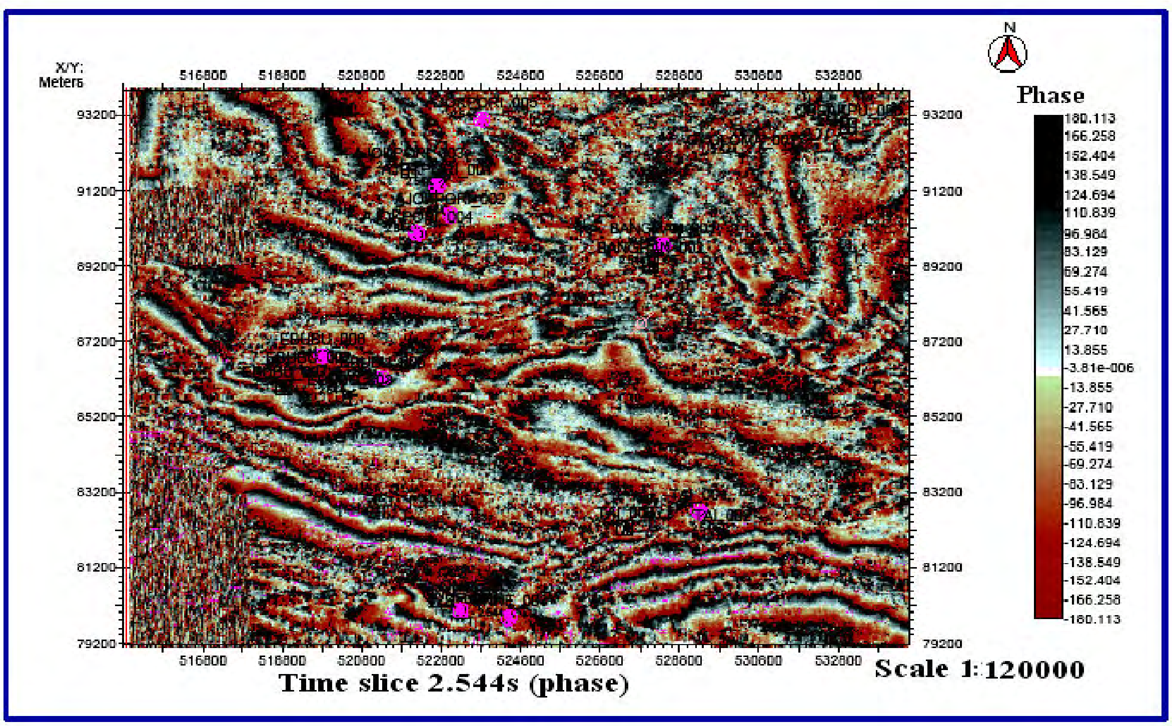
The LST-1b constitutes the middle aggradational part of the lowstand wedge deposits while the LST-2 facies unit was deposited when depositional conditions gradually changed from fluvial to incorporate open continental shelf setting. It commonly exhibits high amplitude reflections that are not always hydrocarbon indicators. According to Emery and Meyers (1997), Tertiary paralic sequences generally exhibit this seismic signature and in some cases may be due to "tuning effects" or the constructive and destructive interferences of seismic waves reflected from the top and base of a given reflector especially when the bed thickness is in the range of 1/4λ of the dominant frequency. Most existing oil wells do not penetrate beyond the lowstand systems tract most probably due to increasing shale beds thickness with increasing depth, however, some oil wells that are located around channels edges do penetrate the pre-channel sequence. This comprises a paralic sequence with relatively thicker shale beds thus indicating that its upper part is paralic.

The transgressive systems tract (TST) is sub-divisible into upper and lower sections that are slightly different in their lithofacies stacking patterns. Its upper part consists of predominantly thick sandstone beds that sometimes exceed 400ft (122m) interbedded with relatively thinner shale, silty/clayey sands and sandy clay beds. The lithofacies units exhibit mainly blocky motif with minor intersperses of bell and funnel shapes. The lower part consists of a paralic sequence in which the sandstone and shale beds are relatively thinner than in its upper part. This systems tract exhibits sub-parallel to parallel, continuous, moderate to high amplitude reflections. It is inferred deposited when active sedimentation sites shifted gradually from intra-channels to overbank and open shallow continental shelf environment. The D1000 to D9000 reservoirs' facies are located within its paralic sequence (see Figure 4a). They constitute the first set of hydrocarbon reservoirs' facies that are intersected downhole by oil wells within an average depth range of 6000ftss to 7800ftss (1829m to 2378m) in Afam Channel area.

A major condensed section that ranges in thickness from 964ft to1800ft (294m to 549m) extends from an average depth range of 3050ftss to 4950ftss (930m to 1509m) and a time range of 1.05s to 1.46s of the record length. It exhibits mainly a blocky log motif with high GR readings (> 75API) and low resistivity readings (≈30Ω-m). On seismic sections, it exhibits mainly hummocky reflection configuration (Figure 5a). Weber and Daukoru (1985), referred to it as Afam Clay Member. It is inferred deposited when low energy depositional conditions prevailed consequent to maximum water deepening. The localities then became active depocenters of hemipelagic/pelagic sediments while active depocenters of coarser siliciclastics shifted landwards. It is inferred a “type 2 sequence boundary” (see Galloway 1989) that corresponds to the correlative equivalence of a type 1 sequence boundary landward wherein there is coastal onlap. The maximum flooding surface (MFS) is indicated on well logs with drastic changes in readings from that above it that is reflective of a major lithologic change from mainly sandy above to shaly within the condensed section.



(a) A seismic Time Section Showing the Systems Tracts and Facies Units.



(b) A Time Slice (Phase) at 2.544s showing the Depositional Surface during Middle LST.

Fig. 5: A Seismic Section Showing the Seismic Signatures of The Systems Tracts and Facies Units and a Time Slice at 2.544s (Phase) Showing the Geometry of the Paleochanneling System during Middle LST in Afam Channel Area, Niger Delta.

The highstand systems tract exhibits mainly blocky log motif with intersperse of funnel and bell shapes. It consists mainly thick sandstone beds that are intercalated by relatively thinner shale beds, sandy clay and clayey sand. Some sandy beds have thickness up to 500ft (152m), which are characterized by high resistivity readings that are unrelated to hydrocarbon saturation. On seismic sections, it extends from a time range of 0.54s to 1.16s of the record length, while in depth sections, it extends from an average depth range of 2064ftss to 3140ftss (629m to 957m). This depth zone lies within the Benin Formation of the Niger Delta. Its upper part is characterized by continuous, sub-parallel to parallel moderate amplitude reflections which grade gradually to hummocky reflection that characterized the underlying condensed section. This facies unit is inferred deposited mainly in moderate energy depositional setting/condition that is attainable in the littorial to inner neritic zones. Hydrocarbon potential evaluation of its reservoirs' facies does not indicate the occurrence of hydrocarbon therein.

The coastal plain deposits exhibit mainly blocky log motif and generally low gamma ray readings. Lithologic types range from mainly sandstone beds with minor intercalations of shale, sandy shale and shaly sand. On seismic sections, they are characterized with sub-parallel to parallel, continuous, low to moderate amplitude reflections. The lithofacies units are inferred deposited over a wide topset surface that is attainable in the delta plain, shoreface to littorial zones. They lie within a depth range of sea- level to about 1864ft (0-873m) and based on their lithologic character and depths, they conform to the Benin Formation of the Niger Delta. This depth zone is not known to sustain hydrocarbon reservoirs in the Niger Delta.

The Afam Channel area overall facies stacking patterns indicate sedimentation in a shallow ramp setting in which the minimum sea-level fall/base level was at the shelf break. According to Emery and Meyers (1997), when minimum relative sea-level falls is at the offlap break, rivers incise the topsets shelf deposits and a type 1 sequence boundary is developed. This is indicated by the first topset of the succeeding system onlapping the previous topset beds. Afam Channel is located up dip of the position of the offlap break. Depositional conditions are most often broadly uniform in a ramp margin setting, which is typically characterized by a low relief, an extensive shelf area. According to Ladipo (1992), depositional environments in shallow ramp settings are dominated by shallow marine (deltas) to coastal plains. This is as a result of the shallow water depths, which in the case of Niger Delta rarely exceed middle neritic realms in the central areas.

Reservoirs' Facies/Hydrocarbon Reservoirs

The hydrocarbon reservoirs' facies are located within the paralic sequence of the lower transgressive through to the lowstand systems tracts and the upper pre-channel sequence within an average depth range of 6000ftss to 11800ftss (1829m to 3536m). They comprise: (i) D1000 to D9000 reservoirs' facies within the lower transgressive systems tract, (ii) E1000 to E9000 reservoirs' facies located within the upper part of the lowstand systems tract, (iii) F1000 to F6000 reservoirs' facies located within the lower lowstand systems tracts (see Figures 4a&b), and (iv) G and K reservoirs' facies within the pre-channel sequence. The beds' thickness ranges from 15ft to 386ft with porosity ranging from 0.28 to 0.41. The reservoirs' facies that are located within the pre-channel paralic sequence are very thin, often less than 80ft in thickness. Figure 6 presents inter-wells' correlation of hydrocarbons reservoirs' facies that are located within the lower transgressive and the lowstand systems tracts in Korokoro Field, Afam Channel area. Six hydrocarbon reservoirs' facies comprising D6000, E1000, E2000, E4000, E5000 and E7000 are identifiable therein in a depth range of 8250ftss to 9925ftss. Each hydrocarbon reservoir's facies is usually most prolific in oil wells that intercepted it in the apex area of each structural high. The multi-stacked patterns of these hydrocarbon reservoirs' facies do result in multi-reservoirs producing wells, however, the prolific level of each oil well is determined by how many of them it intersects optimally. Most marginal discoveries were recorded in oil wells that are located towards the flanks of the major structural highs and channel edges. Lithofacies logs signatures are quite similar at each oil well location, thereby indicating a contemporaneous deposition in different arms of the paleochanneling system. Inter-wells reservoirs' connectivity is often disrupted by structural deformation or they were deposited contemporaneously in different arms of the paleochanneling system hence separated by interfluves. Hydrocarbon potentials evaluation of reservoirs' facies within the stratigraphic succession less than 6000ftss (1829m) does not indicate hydrocarbon occurrences. This is ascribed to the thick sand bodies that are most often in excess of 300ft, arealy extensive with few faults of obscure throws that probably do not constitute perfect permeability barriers to petroleum migration.

One-Dimensional Seismic Modeling (Synthetic Seismogram)

The synthetic seismograms generated were used to relate seismic reflection characters to lithologies and hydrocarbon reservoirs' facies starting at oil wells' locations. This aided stratigraphic interpretation as well as mapping hydrocarbon reservoirs' facies as it enabled the discrimination of significant reflection events arising from lithologic boundaries from those arising from hydrocarbons reservoirs' facies. Hydrocarbon (HC) reservoirs' facies are indicated by a change in polarity, increase in acoustic impedance and interval velocities respectively between two adjacent major events alongside with appreciable increases in resistivity logs readings (Rxo and Rt). Moreover, the reflection event is less persistent than that arising from lithologic boundaries. The inclusion of GR or SP as reference logs further enhanced the correlation of the reflectivity with lithologies and the subsequent tying to the seismic field data. Figure 7 is a synthetic seismogram of Ajokpri_001 well in the study area. The following diagnostic features are observable on the

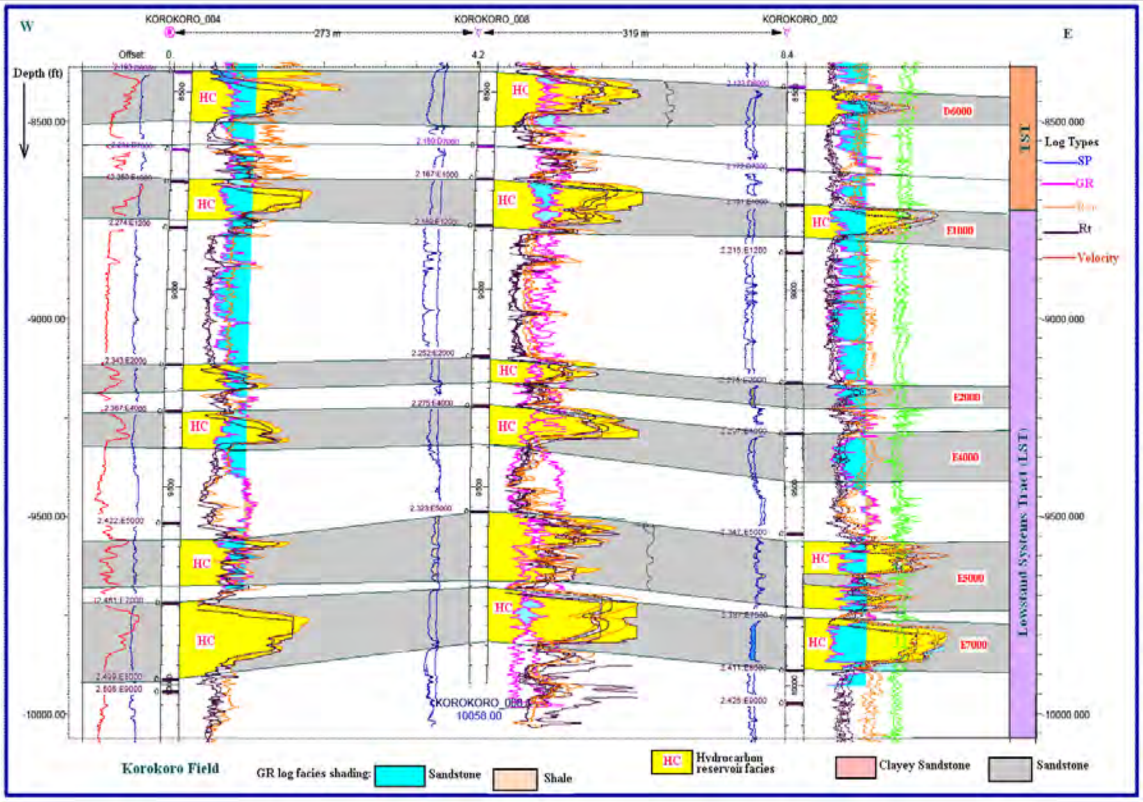


Fig. 6: A Lithofacies Correlation of Reservoirs' Facies in Korokoro Field, Afam Channel Area, Niger Delta.

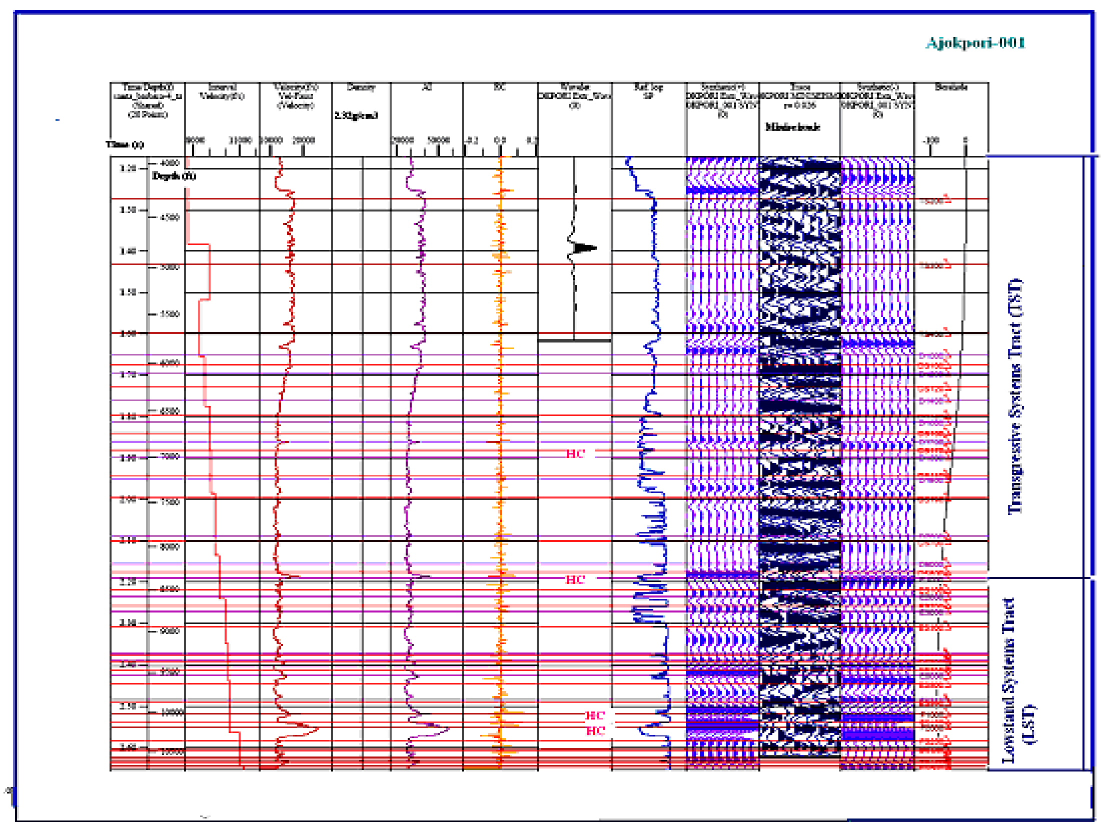


Fig. 7: A Synthetic Seismogram of Ajokpori-001 Well, Afam Channel Area, Niger Delta.

synthetic seismogram: (i) in a relatively thick and uniform lithologic unit, the amplitude is suppressed, for instance the time interval of 1.28s-1.59s that consists of thick lithofacies units of the upper transgressive systems tract, (ii) the paralic sequence is expressed as a series of high amplitude events: peaks and troughs (time interval 2.10s to 2.69s), with the presence of hydrocarbon increasing the unit's peak-trough ratio as indicated therein.

Mapping of Hydrocarbon Reservoirs' Facies on Seismic Time Sections

Hydrocarbons reservoirs' facies indicated on well logs were mapped on seismic time sections through areal tracing of their associated reflection characters starting at oil wells locations thereby enabling the determination of each reservoir areal extent, geometry, trapping mechanism and interconnectivity. The trapping mechanisms range from trapping against channel edges/faults, structural high, lithofacies thinning or converging up dip or a combination of structural and stratigraphic features. Marginal oil wells are ascribed to their non optimal locations as they do not intercept optimally enough hydrocarbon reservoirs' facies. Figure terpreted seismic section of crossline 2551 showing hydrocarbon reservoirs' facies within the LST facies units in a time range of 1.84s to 2.32s in Ebubu Field. They thin gradually and become shaly westward from Ebubu-005 as indicated by the gradually diminishing reflection amplitude towards Ebubu-007. In this field, Ebubu-005 is a producing well, while Ebubu-002 and Ebubu-007 are marginal wells. Most existing oil wells within the Afam Channel area have an average bottom hole depth of 10400ftss thereby excluding the prolific F-reservoirs' facies that are commonly encountered at an average depth range of 10600ftss to 12000ftss, except arched by diapiric structures to shallow depths. These reservoirs' facies are well intercepted in Ajokpori Field where the average bottom hole depth is 11600ftss and Korokoro-010 well with a bottom hole depth of 12000ftss. Some marginal oil wells production could be improved upon by increasing their bottom hole depths if problems associated with overpressured shales are tackled. The D-reservoirs' facies are thicker, areally wide and exhibiting mainly sheet and sheet drape geometries. Consequently, where there are no lateral permeability barrier or structural trapping mechanism, they are generally barren of petroleum. The E and F reservoirs facies generally exhibit wedge, lense and mound geometries. They were deposited mainly as point bars and channel bars during sea-level lowstand when sedimentation was mainly intra-channels. They are generally more prolific than the D- reservoirs' facies.

Stratigraphic and Combination Traps in Afam Channel Area

Petroleum traps in Afam Channel area can be classified into three basic types namely structural, stratigraphic and combination traps distributed as follows: 45% are combination traps, 35% are structural traps while 20% are stratigraphic traps. The structural traps consist of structural closures against major faults that often bound structural highs. The stratigraphic traps comprise lateral lithofacies changes accompanying lithofacies units building up dip and over structural highs, lithofacies terminating against channel edges and lithofacies changes within the structural highs. Some oil wells are located based on lateral lithofacies changes in transiting from channel to pre-channel sequence that often creates permeability barriers. These oil wells often penetrate appreciably into the pre-channel sequence. The combination traps are more common and the trapping mechanism involves the interplays of structural folding, faulting and lateral lithofacies changes. Sometimes, the three basic types of petroleum traps are found in a single oil field. Figure 9 presents models of some stratigraphic and combination traps in Afam Channel area. These range from structural highs bounded by faults within channel fills, lateral lithofacies change and across channels edges/fault, and lithofacies units thinning up dip of a structural high. In all these traps, the target reservoirs' facies are those lying within the paralic sequence that extends from the lower transgressive through to the lowstand systems tracts and the upper pre-channel sequence.

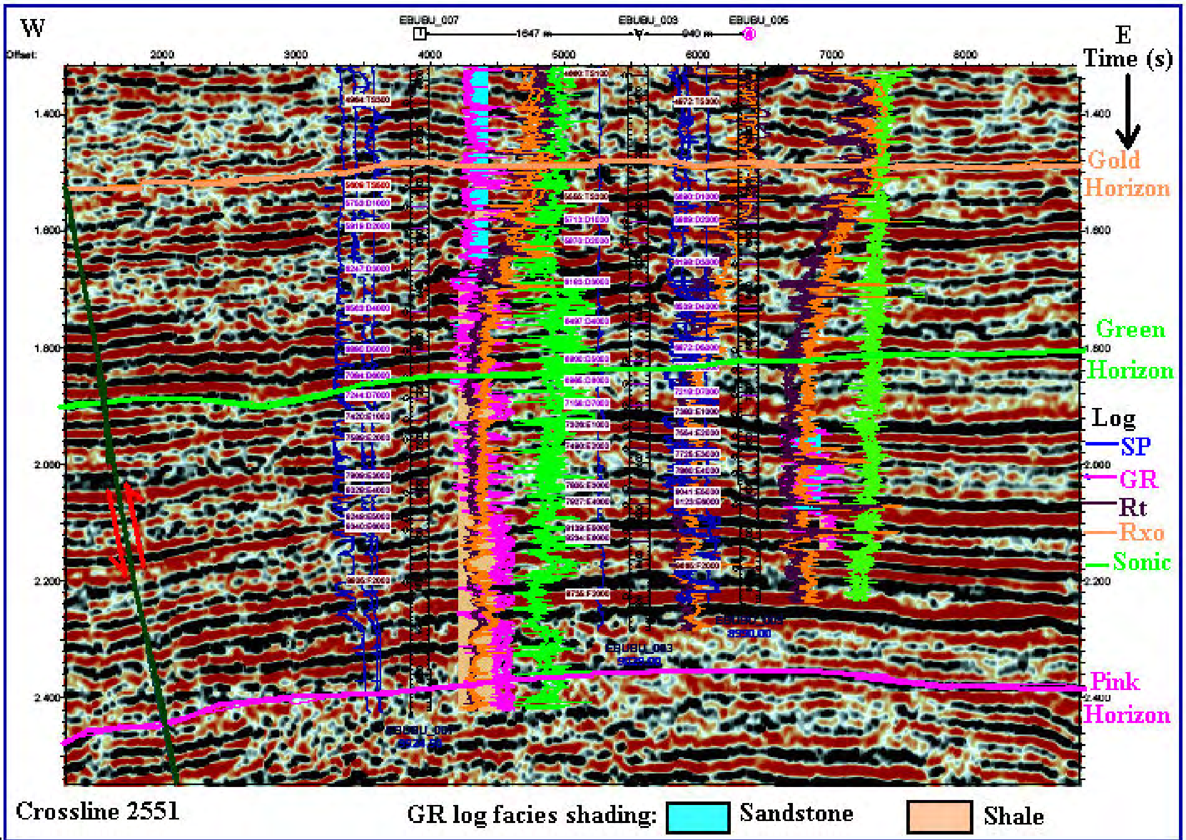


Fig. 8: A Seismic Time Section of Crossline 2551 Showing Hydrocarbon Reservoirs' Facies in Ebubu Field, Afam Channel, Niger Delta.

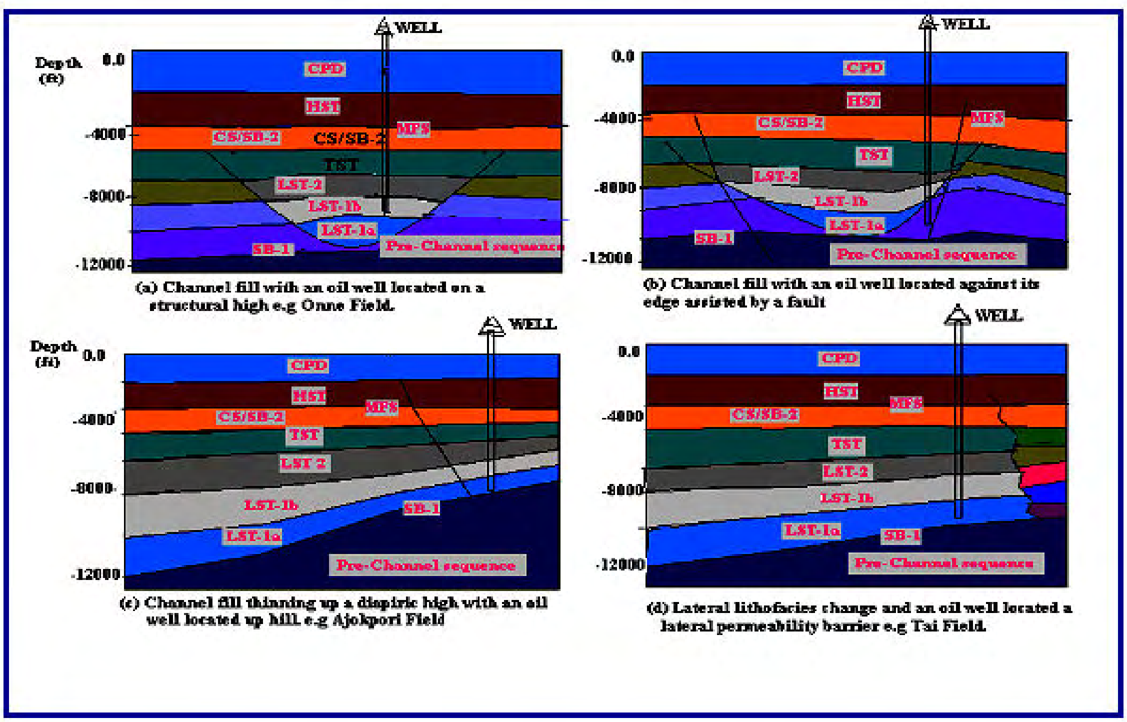


Fig. 9: Models of Stratigraphic and Combination Traps in Afam Channel Area, Niger Delta.

CONCLUSION

The Afam Channel consists of several amalgamated incised fluvial channels on a major submarine canyon/gully on the continental shelf that became exposed during sea-level lowstand and backfilled by sediments of the Miocene age in the succeeding marine transgression. The entire stratigraphic fill is sub-divisible into three systems tracts comprising lowstand, transgressive and highstand systems tracts capped to the earth's surface by the coastal plain deposits. A type 1 sequence boundary separates the channel sequence from the pre-channel sequence while a major condensed section separates the transgressive from the highstand systems tracts. The entire channel fill sub-division is typical of a minimum sea-level fall at the shelf break over a ramp margin that characteristically produces a type 1 sequence boundary. The study area falls within the realm of lowstand wedge deposits. The lower part of the channel fill sequence extending from lower transgressive through to the lowstand systems tracts and the upper pre-channel sequence consists of a paralic sequence while the upper part lithologic types comprise mainly thick sandstone beds intercalated with shale beds and gradational lithologies of sandy shale and shaly sands.

The reservoirs' facies are located within the paralic sequence of the lower transgressive through to the lowstand systems tracts and the upper pre-channel sequence in a depth range of approximately 6000ftss to 11800ftss. Hydrocarbon reservoirs' facies are indicated by polarity reversal, increase in acoustic impedance contrast, interval velocity and resistivity logs readings respectively between two adjacent major reflection events. These reflection characters serve as tools for the determination of whether they are optimally intercepted or out rightly bypassed. Reservoirs geometries range from wedge, lenses and mounds within the lowstand systems tract, hence having limited width/lateral extent and mainly sheets/sheet drapes within the transgressive system tract. The basal part of the lowstand systems tract is composed mainly of shale, which may be worrisome in petroleum exploration because of over- pressured shale zones. Lithostratigraphic depth sections indicate inter-wells reservoirs' connectivity within an oil field, however, inter-fields reservoirs' connectivity is quite rare. Virtually all potentially viable structural petroleum entrapment features have been test drilled. New prospects lie within stratigraphic and combination traps which were hitherto ignored because of the problems of intercepting optimally enough hydrocarbon reservoirs' facies at each oil well location. Carefully designed deviated wells will aid in tackling this problem.

ACKNOWLEDGEMENT

The authors are grateful to Shell Petroleum Development Company (SPDC) Portharcourt for providing the data sets that were used in this research.

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