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APPLICATION OF TRANSGRESSIVE-REGRESSIVE TECHNIQUE IN SEQUENCE STRATIGRAPHIC ANALYSIS AND ITS IMPLICATION FOR IN-FILL WELL LOCATIONS: A CASE STUDY FROM "IMAEMI" FIELD, OFFSHORE NIGER DELTA

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Abstract

The transgressive-regressive technique was used to delineate sequence boundaries identified on well logs from 25 wells in "Imaemi Field", offshore Niger Delta. The study was aimed at enhancing current understanding of the importance of reservoir basinal sequences in exploration. Eleven sequence boundaries; Sequence Boundary-1 through to Sequence Boundary-11 (SB-1 to SB-11) were identified and delineated in the field. Reservoir architectural analysis yielded twenty four vertically stacked, youngest to oldest reservoir bodies (A-Sand through Q-Sand) within channel-fill, abandonment phase, delta plain and prodelta depositional settings. The transgressive-regressive technique presents a simple scientific approach to anatomize the Niger Delta stratigraphic sequences. This approach significantly fast-tracked the pace of characterizing reservoirs in the studied field, fosters prediction of sand body geometry and continuity within a depositional architecture and can enhance selection of new in-fill wells locations in a field. For example, the geologic continuity of the H-Sand reservoir, including its hydrocarbon spatial distribution in the field is predictable. The H-Sand, I-Sand and N-Sand can be selected as in-fill wells objectives at some locations between well Imaemi-01 and well Imaemi-19. H-Sand, I-Sand and J-Sand are suitable objectives between Imaemi-27 and Imaemi-02, while H-Sand, M-Sand and N-Sand can be targeted between Imaemi-33 and Imaemi-31 wells in the field.

Keywords*: Sequence stratigraphy; Transgressive-Regressive; In-fill Well Location; Stratigraphic Architecture; Offshore Niger Delta.*

1. Introduction

The stratigraphic architecture of a basin often reflects the complexity of interplay among sedimentation, eustatic sea-level changes, tectonism and paleotopography. Sequel to the emergence of modern sequence stratigraphic analysis, many workers had adopted several techniques to evaluate the sedimentary fill and architecture of basins. For example, Type 1 and Type 2 depositional sequences [1] and Genetic stratigraphic sequence type which used maximum flooding surfaces as sequence boundaries [2]. A later sequence stratigraphic methodology utilized the transgressive-regressive sequence boundaries, based on changes from prograding to retrograding parasequence set stacking pattern [3].

Sediment supply, accommodation space and relative sea level fluctuations in the Niger Delta created repetitive vertical stacking of marine interbedded silts, sands and clays followed by shore-face sand, then coastal plain deposits; each stack being an autocyclic fourth-order sequence [4-5]. It has been recognized that stratigraphic architecture is signified by the degree of third–order cycles or sequences, which are fundamental units of regional subsurface stratigraphic subdivision and correlation [5]. Mazzullo [6], for instance, attributed the stratigraphic and depositional architecture of Chase Group in Mid–Continent USA, to interplay among paleobathymetry, glacio–eustasy and periodic syndepositional tectonism. Using wireline logs from

"Imaemi" field, offshore Niger Delta, this study employed the transgressive-regressive technique to delineate sequence stratigraphic boundaries. The study also highlights the importance of the technique as an invaluable tool for reservoir characterization and well planning.

2. Study area and the geologic setting of the Niger Delta

"Imaemi" Field is located 8.00 km offshore, western part of the Niger Delta at water depth of approximately 9 m (29.5 ft). The field is situated in the palaeogeographic zone referred to as the Upper Miocene/Pliocene and Pliocene/Pleistocene of the delta formation cycle [7]. In the Niger Delta, there are the Northern depobelt, Greater Ughelli, Central Swamp, Coastal Swamp and Offshore depobelts. These depobelts occur in onshore, continental shelf and deep offshore environments, determined by regional faults [5]. They defined the structural styles and zones in the Niger Delta. These are known as the extensional, transitional and compressional zones, characterized by three categories of structural styles; growth faults, diapirs and toe-thrust structures respectively. Imaemi Field is in the continental shelf, shallow offshore depobelt (Fig. 1) distinguished by growth faults. The study area is within the extensional province of the shelf.

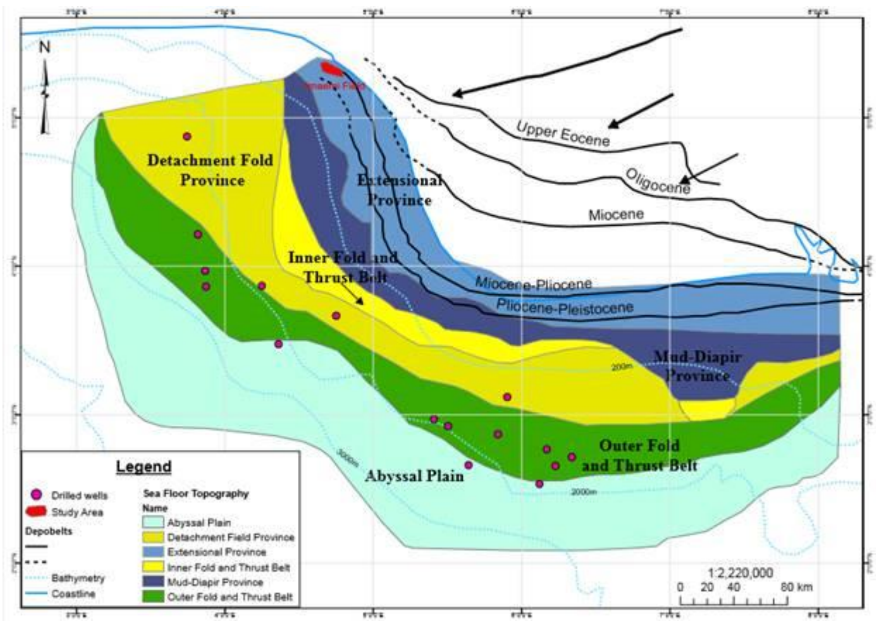

Figure 1. A structural map of the Niger Delta region, showing the study area *(Modified from Tuttle et al. [47]; Corredor et al.[44]; Kostenko et al. [46])*.

The tectonic framework of the Niger Delta may be understood within the context of the African continental margin. A host of rift systems had developed, associated with pre-Cretaceous lineaments in the lithosphere, which were zones of pre-existing weakness [8]. These resulted in the parting of the Atlantic Ocean in the Cretaceous. The Tertiary Niger Delta covers an area of approximately 75,000 km^2 (28, 957 sq. miles) In the east, the delta is bounded by a line of volcanic rocks comprising the Cameroon volcanic zone and Guinea ridge [7], with structures like the Calabar flank, a jigsaw of NW–SE trending Ikang Trough (Fig. 2), Itu High and the Calabar Hinge Line [5], and the Abakaliki Trough [9-10]. Westward, the delta complex fuses across the Benin hinge line and Okitipupa high into the Dahomey basin. The Chain and Charcot oceanic transform faults helped the Benue Trough growth, while transform fault propagation controlled Niger Delta subsidence [5]. The Niger Delta generally fits the overlying, earlier transform basin systems of the Atlantic-type passive margin basin classification [11]. Three major sedimentary cycles occurred in the Niger Delta since Early Cretaceous [12]. The Late Maestrichtian–Paleocene transgression terminated the second cycle and marked the beginning of the third depositional cycle. The Tertiary Niger Delta is a sedimentary deposit formed as a complex regressive offlap sequence of clastic sediments ranging in thickness from

9000 – 12000 m (29528 – 39370 ft). Short and Stauble [9] first named the three subsurface stratigraphic units as Akata, Agbada and Benin Formations from bottom to the top, in the order of decreasing age in the modern or Cenozoic Niger Delta.

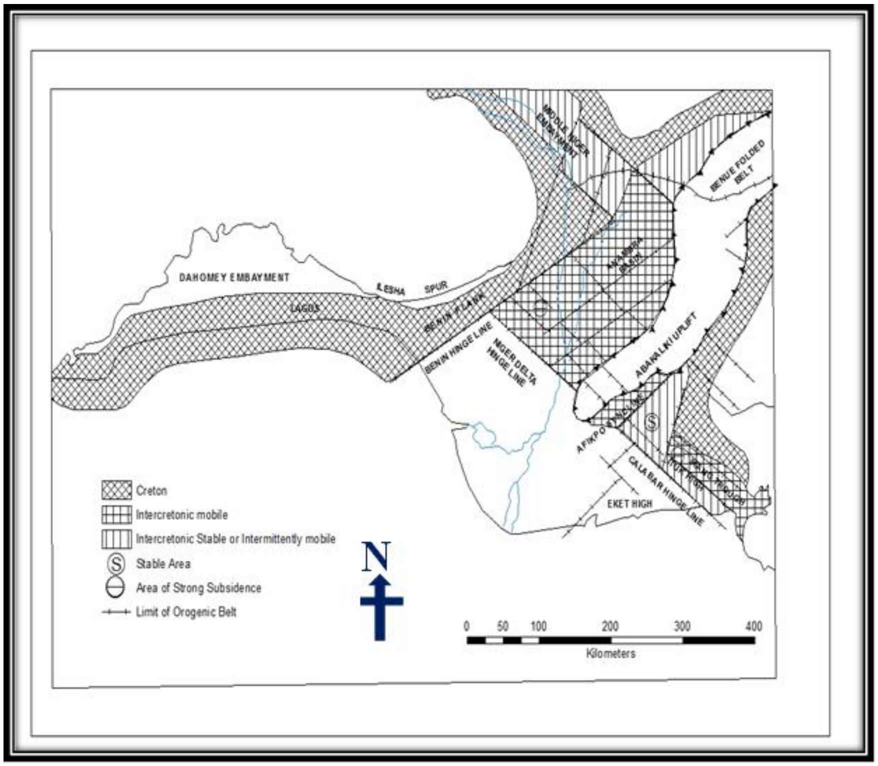

Figure 2. Megatectonic Frame: Campanian to Eocene, Showing Prominent Bounding Structures of the Niger Delta *(After Murat [12])*

2.1. Akata Formation

The Akata Formation is a massive marine shale or clay, often overpressured and 0 - 6000 m (0 – 19685 ft) thick. Its deposition began during the Palaeocene transgression and it extends over the entire Niger Delta basin, outcropping along its edges. It is a prodelta marine megafacies, comprising of gray shale, occasional sandstone and siltstone, with plant remains at the top [5,7,13]. Its sandstone units occur as thin lenses close to the contact of the overlying Agbada Formation.

2.2. Agbada Formation

The Agbada Formation contains the main hydrocarbon reservoirs in the Niger Delta [14-16]. The formation is a paralic sequence, characterized by alternation of sandstones and shales, diagnostic of environments distinguished by differential subsidence, variation in sediment supply and shift in the depositional axis [7,9,13,17] The alternation of fine and coarse clastics provides multiple reservoir stratigraphic seal couplets, while structural traps are related to rollovers and growth faults [17]. It is a delta front lithofacies, made of several offlap rhythms [7], unconsolidated to fairly consolidated point bars, distributary channels and coastal barriers. The prevalence of growth faults coupled with facies changes led to structural and stratigraphic traps acting together in many of the reservoirs and influence depth to sand bodies.

2.3. Benin Formation

The Benin Formation is the topmost formation in the Niger Delta, extending from the west across the whole delta area and southward beyond the present coastline. This Formation has been variously reported in the literature [5,7,9,13,18]. It has been described to consist of massive continental sands and gravels (over 90%), partly unconsolidated, coarse-grained, gravelly to locally fine-grained sand stone. Asseez [13] identified point bars, channel fills, natural levees, backswamp deposits and oxbow fills, within this formation, which are indicative of the variability of the shallow water depositional medium. Dearth of fauna contents constitutes dating difficulty [7], although an age range of Oligocene to Recent is often accepted. The formation has five clay members in the eastern Niger Delta and Opuama in the west [5,18]. Only traces of hydrocarbon shows have been known in it and these are mainly towards its base [7].

3. Historical development of the concept of sequence stratigraphy

Stratigraphy describes the vertical and lateral relationships of rocks. Embry [19] gave a working definition of the subject. He noted that sequence stratigraphy consists of the recognition and correlation of changes in depositional trends in the rock record. These changes generated by the interplay of sedimentation and shifting base level, are recognized by sedimentological criteria and geometrical relationships. One of the earliest known proponents of this concept was Nicholaus Steno, who identified that strata are formed as heavy particles settle out of a fluid. Steno's enduring stratigraphic principles are: that younger layers lie on top of older layers; layers are initially horizontal, and continue until they run into a barrier [20]. A notable addition to stratigraphy was from Gressly, especially in the areas of facies concept and applications, stratigraphic correlation and palaeogeographic reconstruction [21]

Modern stratigraphy began in the late 18th century, and was driven by two contrasting research models or cognitive styles; inductive and the deductive models [22-27]. The inductive stratigraphy led to the creation of a data base of stratigraphic units, and constitutes the basis of modern chronostratigraphic time scale [27]. The deductive models began with Hutton's uniformitarianism, and employed underlying geologic controls to explain Earth processes. Deductive school of thought sought evidence of regularity or cyclicity in the Earth processes or "the pulse of the earth", which includes the modern global-eustasy model [27].

A distinguished German philosopher, Heidegger [26] explained geological practices in a process termed the hermeneutic circle. This involves a sequence of induction and deduction. The iterative processes incorporate observation, generalization and theorizing or induction, then construction of hypotheses and seeking of new observation to test and abandon or refine the theory or deduction. Fairbridge [29] summarized the main mechanisms of sea level changes. He stated that tectonic hypothesis is localized to a region, while eustatic or sea level changes are widespread and apply worldwide. Fairbridge [29] therefore, proposed integration of multidisciplinary theory for solution to stratigraphic concepts.

Earlier stratigraphic hypotheses were harmonized and its modern state enunciated [1,30-35]. Sloss [30] for instance, grouped layers of rocks into unconformity-bounded sequences based on lithology. In 1977 Vail, a student of Sloss introduced seismic stratigraphy, by interpreting unconformities based on tying together global sea-level change, local relative sea-level change and seismic reflection patterns. The end result of Vail's work was the production of global charts for the distribution of major unconformities derived from seismic [36]. This new application of stratigraphy fosters linkage of seismic, log, fossil and outcrop data at local, regional and global scale.

Modern work on the chronostratigraphic time scale is based on empirical principles, culminating in the definition of global section and boundary stratotypes for the major chronostratigraphic units [37]. Presently, sequence stratigraphic concepts as recognized by scientists are based on the assumption that sea level changes are the predominant control on stratigraphic architecture, geometries and facies, while they admit that tectonics, subsidence, isostasy and compaction contribute to creation of space for sediment accommodation. As noted above, sequence stratigraphy depends on the intricate subdivision of the Earth's sedimentary deposits into layers or sequences. These sequences vary in types; hence, the succeeding section focuses on sequence types.

4. Stratigraphic sequence types

There are four stratigraphic sequence types, each with a different set of bounding surfaces. Vail *et al.* [1] defined Types 1 and 2 depositional sequences. Galloway [2] suggested genetic stratigraphic sequence type, while Embry and Johannessen [3] proposed the Transgressive-Regressive Sequence. The Type 1 sequence uses subaerial unconformity as the unconformable portion of the boundary. Its timeline matches the start of base level fall for correlative conformity. It is difficult to apply this sequence type due to difficulty of objectively identifying a timeline that coincides with the start of base level fall [19]. The Type 2 sequence similarly used subaerial unconformity as the unconformable portion of the boundary, but utilizes a timeline equivalent to the end of base level fall for the correlative conformity. Embry [19] observes difficulty to identify time line equivalent to end of base level fall or start of base level rise. Galloway [2] proposed the application of ma-ximum flooding surfaces (MFS) as sequence boundaries and termed the unit a Genetic Stratigraphic Sequence. The advantage of this method [19] includes alleviation of subjectivity in boundary recognition, inherent in Type 1 and Type 2 sequence types, since maximum flooding sequence is determined by objective scientific means. The limitation of the genetic sequence is lack of coherency in basin margins, because subaerial unconformity can occur within the sequence. Embry and Johannessen [3] initiated the transgressive-regressive sequence. It uses the subaerial unconformity as the conformable portion of the sequence boundary and the maximum regressive surface as the correlative conformity [19]. The emphasis here is on the use of changes in depositional trends as boundaries to define the transgressive-regressive sequence type (Table 1). In this ca-se, transgressive system tract may be below and a regressive systems tract above.

Table 1. A Comparison of System Tract Schemes for a Type 1 Depositional Sequence, a Type 2,Depositional Sequence and a Transgressive-Regressive Sequence

Event	Type 1	Type 2	T-R
Start Transgression			SB
Start B.L. Rise	LST late / early	LST SB FRST (FSST)	RST
Start B.L. Fall	SB		
Start Regression	HST TST	HST TST	TST
Start Transgression			SB
Start B.L. Rise	LST late / early	LST SB	RST

LST: Lowstand System Tract; TST: Transgressive Systems Tract; HST: Highstand Systems; Tract; FRST: Forced Regressive Systems Tract; FSST: Falling Sea Level Systems Tract; RST:Regressive Systems Tract; SB: Sequence Boundary; (T-R): Transgressive-Regressive Sequence (Modified from [3,19]

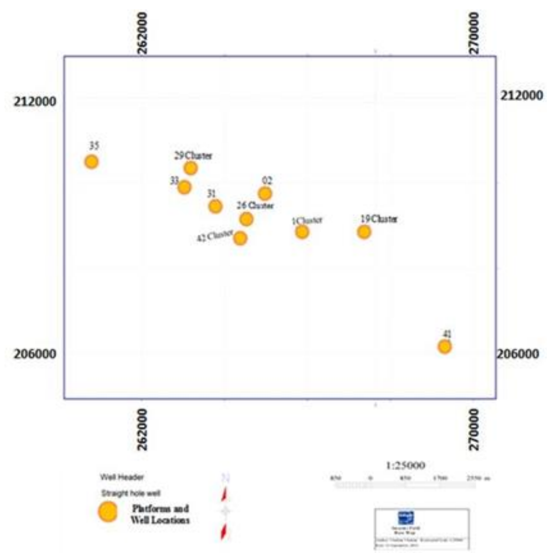

Figure 3. Base map of Imaemi Field showing the location of 10 Platforms from which 25 wells used in this study were drilled and the surface positions of the wells

5. Methodology

The Gamma Ray, Resistivity, and Neutron-Density logs were combined to pick and correlate stratigraphic surfaces and sequence boundaries. At intervals where only Gamma Ray log curve exists, it was used to define changes from prograding parasequence set to retrograding parasequence set stacking pattern [3,19,38]. Changes in depositional trends were used as boundaries [38]. For instance, change from sedimentation to subaerial erosion or change from transgressive or deepening of the environment to a regressive or shallowing upward trend. Thus, subaerial unconformity was seen as change from sedimentation to subaerial erosion [38]. Maximum flooding surfaces were defined by change from transgression to regression. The four log curves were used thus;

1) Flooding surfaces (FS), were picked based on Neutron-Density separations and Resistivity readings. The interval with highest Neutron-Density values and related lowest Resistivity reading close to other flooding surfaces was picked as the Maximum Flooding Surface (MFS).

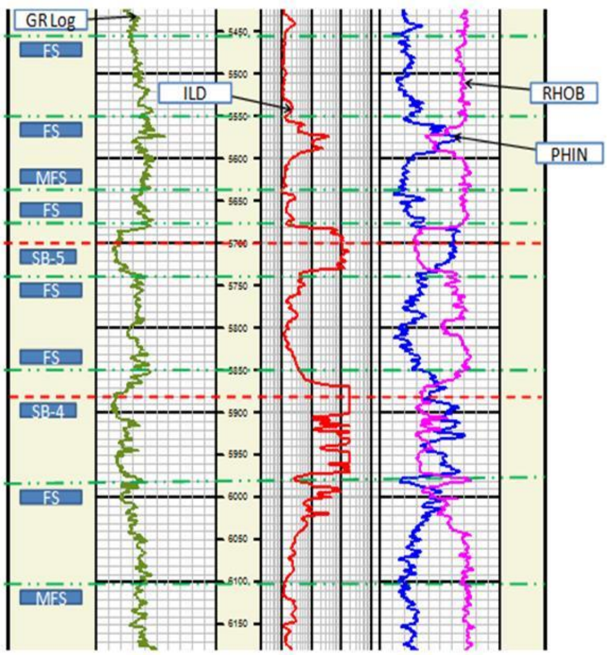

Figure 4. Part of Imaemi-01 Well Log Showing Positions of Flooding Surfaces (FS),Maximum Flooding Surfaces (MFS) and Sequence Boundaries (SB) Delineated and PickedUsing the Transgressive-Regressive Method. Note: ILD = Deep Induction Log; GR =Gamma Ray; RHOB = Bulk Density; PHIN = Neutron Porosity Log; Depth values on the Log are given in feet.

2) Trends of upward-increasing FS Resistivity and upward-decreasing FS Neutron-Density correspond to forward stepping or progradation of delta cycles. Conversely, trends of decreasing FS Resistivity and increasing FS Neutron-Density correspond to a back-stepping or retrogradation of the delta. The two patterns are separated by a sequence boundary (SB), a surface that reflects time of maximum basinward shift of the shoreline position within the cycle. Stacking patterns were used to link, FS, MFS and SB. This approach was used to delineate sequences in the field (Fig. 4), as presented in the succeeding section. The base of Benin Formation, that is, the top of the underlying Agbada Formation was first defined and used as a datum prior to picking of tops and bases of reservoirs. The datum was identified in each well by marked drop in typically high Resistivity reading of the fresh to brackish water of the Benin Formation with concomitant change in Gamma Ray log from dominantly low reading sandy sections to high Gamma Ray value and low Resistivity shale break. The shale break or layer is directly succeeded by transitional paralic Agbada sequences.

6. Sequence Stratigraphy of Imaemi Field

6.1. Sequence Boundary 1

Sequence 1 is the lowest sequence boundary picked in this work and is correlated field-wide along northwest-southeast portion or in the coastline direction (Fig. 5). The sequence boundary was picked within N-Sand. It is well preserved to the southeast and gradually eroded to the northwest part of the field. Sequence Boundary 1 separates a lower prograding parasequence stack from an aggrading upper transgressive parasequence. Below the sequence boundary are lobes of upward coarsening channel sands, bifurcated by shale lenses. The sequence boundary depicts the time of the lowest sea mark from the land or position of maximum sea retreat.

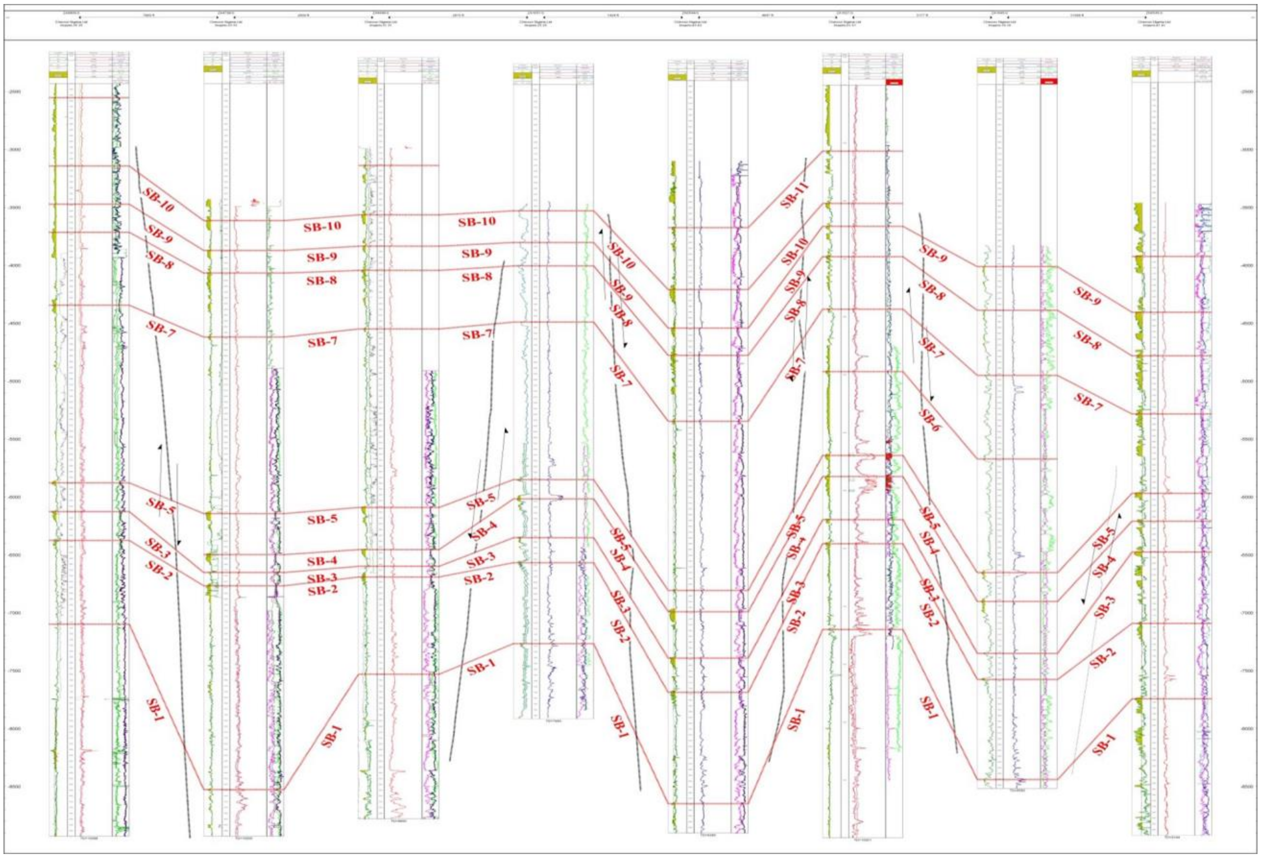

Figure 5. The Sequence Stratigraphy of Imaemi Field Showing 11 Sequence Boundaries, SB-1 to SB-11 Picked on Well Logs

6.2. Sequence Boundary 2

Sequence Boundary 2 starts with an erosional base and comprises an aggradational stacking pattern parasequence. It formed over a long time with relatively stable eustatic changes, reflected as minor regressions and transgressions which resulted in agradded beds of fine sand, silty sand, shaly sand, silt and shale. Within this sequence occurs deep marine facies transiting to marine shoreface facies, with M2-Sand, M1-Sand, M-Sand and the L-Sand as the main reservoirs. Its top represents a progradational stacking pattern as the shoreline regressed, resulting in sand deposition that was abruptly terminated by marine transgression, giving L-Sand sharp contact with overlying marine shale bed (Figs. 6 and 7), in the strike and dip sections of Imaemi Field.

6.3. Sequence Boundary 3

This sequence began with subaerial erosional truncation and or channel incision, with basinward shift in environments. The sea level dropped, with flooding surfaces picked in Imaemi-43 at 2359.15 and 2330.50 m (7740.00 and 7646.00 ft) MD, while maximum flooding surfaces, MFS were picked at 2356.10 and 2322.27 m (7730.00 and 7619.00 ft) MD. The sequence boundary, SB 3 at 2282.95 m (7490.00 ft) MD, depicts maximum seaward shift of the shoreline. The main reservoir is the K-Sand, a channel fill with gradational shale to silty sand base to sand rich top. The sequence is preserved in the SE to the NW. It pinches to thin lenticular shaly bed by erosion at Imaemi-31 and 33 wells.

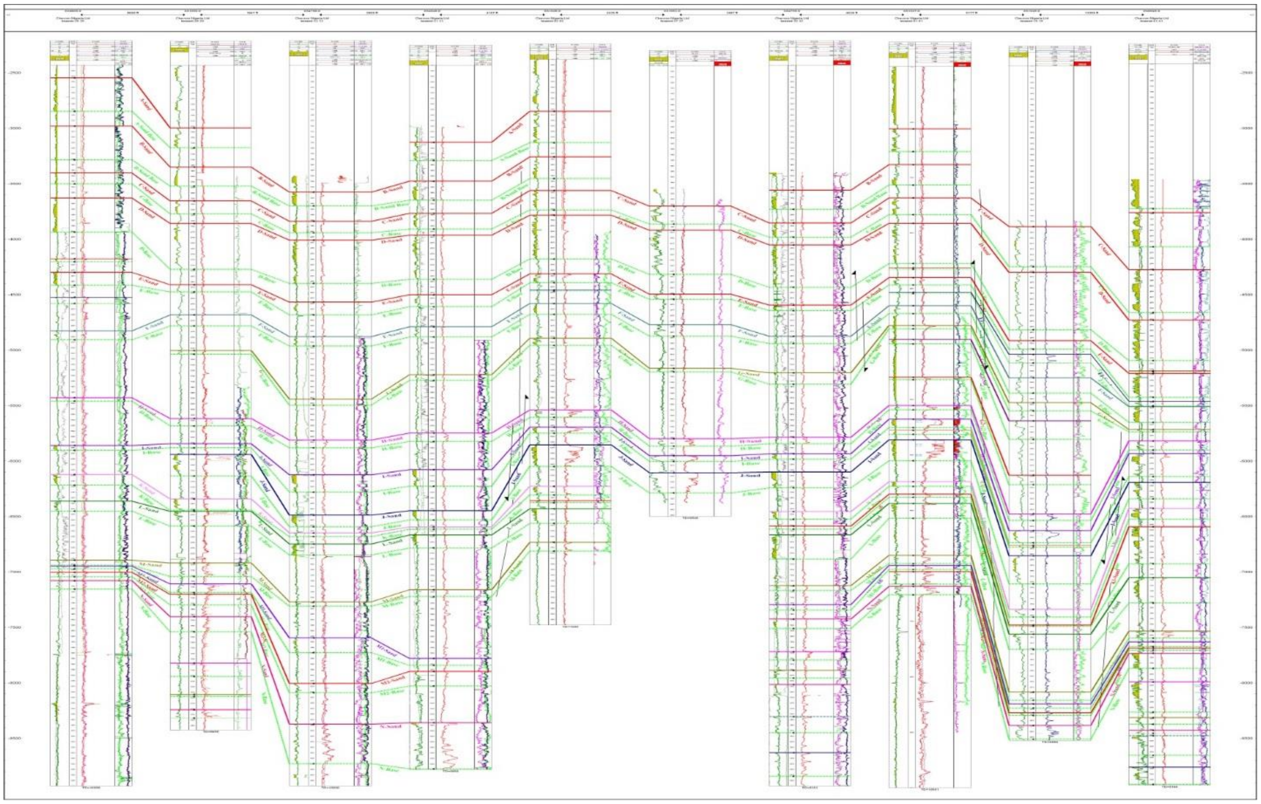

Figure 6. Stratigraphic Cross Section Along Strike, NW–SE Direction in Imaemi Field, Showing the Architectural Stacking Pattern of the Reservoirs, Tops and Bottoms of the Reservoirs and Non-Reservoir Units

6.4. Sequence Boundary 4

Transgression prompted erosion of the top layer of K-Sand reservoir, prior to deposition of shale as energy waned. Flooding surfaces, FS were observed at 1903.17 m (6244.00 ft) MD, 1898.90 m (6230.00 ft) MD, 1892.20 m (6208.01 ft) MD, 1875.74 m (6154.00 ft) MD, and 1860.19 m (6103.00 ft) MD in Imaemi-01. The MFS was also observed at 1886.71 m (6190.00 ft) MD in Imaemi-01, followed by gradual eustatic sea level lowering, which concomitantly increased depositional energy and shallowing of the water column, while shale beds at the base steadily improved in sand content. There were short-lived switches of transgressions. Thus, the sand-rich top became bifurcated by thin lenticular shale beds. The reservoir interval here is the J-Sand.

6.5. Sequence Boundary 5

Sequence Boundary 5 lies unconformably over Sequence Boundary 4 and has the I-Sand reservoir, with erosional base. It represents another cycle of transgression. In Imaemi-33 the sequence is 106.68 m (350.00 ft) thick. The basal part of the sequence consists of homogenous marine shale to sandy shale. The upper part is a progradational deposit, made of lobes of coarsening upward sand.

6.6. Sequence Boundary 6

This sequence depicts aggradational deposits. It has varied thicknesses due to erosion and palaeogeomorphic setting. It is 221.28 m (725.98 ft) thick in In Imaemi-01 and 299.31 m (981.99 ft) thick in Imaemi-19. Sequence Boundary 6 lies unconformably on I-Sand reservoir, a relatively clean coarsening upward sand and incorporates the H-Sand, G2-Sand and G1-Sand. The H-Sand is very diagnostic, while G2-Sand and G1-Sand are thin lenticular beds, confined to few wells toward the southeast and pinched out to the north, northwest segment of the field.

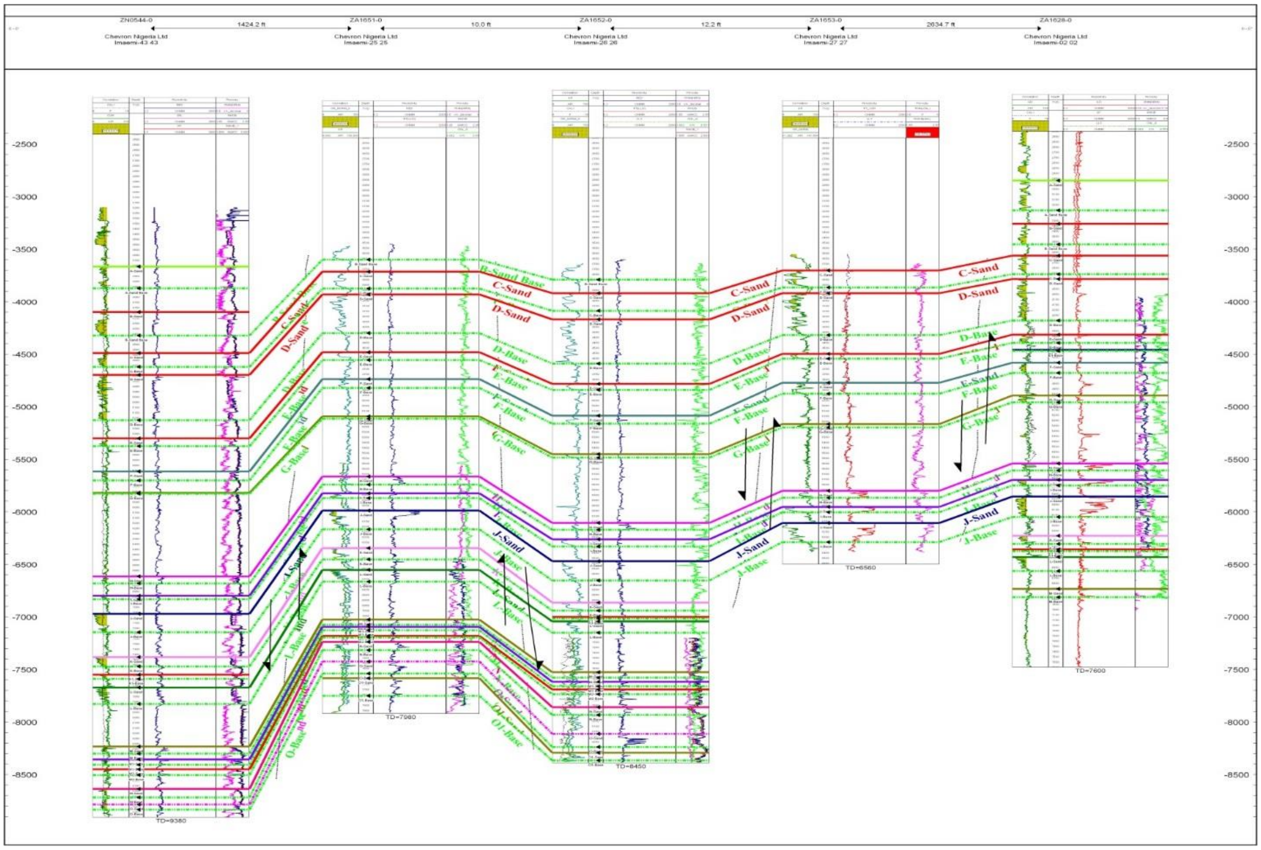

Figure 7. Imaemi Field NNE-SSW Dip Cross Section, Showing the Field Architectural Stacking Pattern, Tops and Bottoms of the Reservoir and Non-Reservoir Units

6.7. Sequence Boundary 7

Sequence Boundary 7 started with transgression and led to the deposition of shale above G1-Sand, a fining upward sand body. The G-Sand, F-Sand, E1-Sand and E-Sand are the main reservoirs in this sequence. The G-Sand coarsens upward and pinched out to the northwest in Imaemi-35, while the F-Sand consists of lobes of coarsening upward fine to silty sand bodies bifurcated by thin lenticular shale beds. The E1-Sand is limited in extent and present in Imaemi-01, 19, and 41 wells. It has two hydrocarbon bearing lobes in Imaemi-19 well. The E-Sand is the uppermost reservoir in this sequence and is extensive. In Imaemi-01 it splits into three coarsening upward sand lobes.

6.8. Sequence Boundary 8

A shale layer representing transgressive system tract marks its base. The sequence has D1 and D-Sand reservoirs. The D1-Sand is sheet-like and limited in extent. The D-Sand consists of six to nine sand lobes aggraded on one another, separated by thin shale lenses, which wedged out in places to result in amalgamated, relatively homogenous thick sand bodies. Each of the sand lobes is coarsening upward in trend. The top of Sequence Boundary 8, picked at the cleanest sand of the lowstand deposit, represents the farthest shoreline shift before another transgression.

6.9. Sequence Boundary 9

This sequence began with the deposition of relatively low resistivity, largely homogenous transgressive marine shale bed of varied thickness, indicative of stable and wide spread event, which accounts for its field-wide correlation. It attained an average thickness of 23.77 m (77.99 ft) within the northwest portion, 20.19 m (66.24 ft) in the southeast and an overall average of 21.95 m (72.01 ft) thick along strike direction in the field. The C-Sand facies in the sequence consists of two main coarsening upward, smooth or slightly serrated lobes, separated by thin shale bed and sharp to cylindrical upper boundaries, as seen in Imaemi-41 and Imaemi-01 wells respectively (Fig. 5).

6.10. Sequence Boundary 10

This sequence unconformably overlies Sequence Boundary 9, with largely homogenous basal shale facies, having 43.99 m (144.32 ft) average thickness from 6 wells (Imaemi-33, 31, 25, 43, 01 and 41), taken in the NW-SE direction. Continued shallowing of the water column due to progradation of the deltaic clastic deposits resulted in high energy and progressive increase in sand content to funnel shape log motif of B-Sand. The sand is bifurcated into upper and lower compartments.

6.11. Sequence Boundary 11

Sequence Boundary 11 is identified in this work to mark the top of the paralic sequence, on which lies the base of a shale bed that separated Agbada Formation from the continental Benin Formation. This sequence is correlated field-wide based on well logs. It consists of the A-Sand as the main reservoir body, homogeneous shale bed underneath this sand and the silty to shaly sand uppermost part of B-Sand. The primary sand, that is, A-Sand within this sequence is serrated into three coarsening upward lobes, each with abrupt top and gradational base.

7. Discussion

The thicknesses of the Benin Formation and Agbada Formations intersected by wells used in this study ranged from 799.00 to 1193 m (2621.39 to 3914.04 ft) for the Benin Formation and up to 1524 m (5000.00 ft) for the Agbada Formation.

The sequence stratigraphic, Transgressive-Regressive technique resulted in the recognition and delineation of Sequence Boundaries (SB1 to SB11), each of approximately 2 to 4 million years cycles. The stratigraphic panel diagram of the field was constructed from H-Sand to N-Sand, incorporating the reservoir and non-reservoir facies with the intercalating shale beds (Fig. 6.2). Correlations of reservoirs and non-reservoir lithofacies in stratigraphic positions within the delineated Sequence Boundaries aided determination of sand geometry, reservoirs heterogeneity; which are factors of scale and complexity [39-40]. Understanding the Sequence Boundaries, their relative positions are vital to reservoirs distribution predictability. The reservoirs are seen to be laterally continuous and bifurcated by variably thick shale intercalations. The laterally continuous nature of the reservoir sands and intercalated shale beds suggest repeated Transgressive-Regressive cycles. Shale breaks with reasonable continuity are known to have a negative influence on hydrocarbon recovery [41-42]. Conversely, the presence of shale lenses tends to limit the danger of early gas or water break called conning.

Infill wells placement may be effectively planned if reservoir distribution knowledge is integrated with spatial spread of fluid contacts in a field. Thus, infill wells can be planned between Platform-19 and Platform-41 wells to the southeast, and Imaemi-35 and Imaemi-29 wells to the northwest.

7.1. Implicatin for hydrocarbon exploration

Further exploration for petroleum resources or search for appraisal or infill well locations, especially in an existing field requires diligent use of available data set. As shown in this study, the Transgressive-Regressive method eases the identification and delineation of sequences around Imaemi Field. Once sequence boundaries are established, reservoir distribution within the sequences in terms of sand bodies' continuity, shaliness and pinch-out directions become predictable. The geologic continuity of the H-Sand reservoir, for instance, coupled with its hydrocarbon spatial distribution in the field is predictable. The H-Sand occurs between SB-5 and SB-6 (Figs. 5, 6 and 7). The reservoir is observed to thicken toward the Southeastern part of the field, while it pinches out to the Northwest (Fig. 6). Similarly, it was noted that the shale content of H-Sand increases from the Southeast to the Northwest. In-fill well locations, where H-Sand reservoir could be targeted were identified as between Imaemi-33 and Imaemi-31, Imaemi-31 and Imaemmi-02, Imaemi-02 and Imaemi-27, Imaemi-27 and Imaemi-32, Imaemi-32 and Imaemi-01 (Figs. 3and 6). It is also possible to predict and target multiple reservoirs for appraisal and in-fill wells drilling through this technique. The H-Sand, I-Sand and N-Sand can be selected as objectives at a location between Imaemi-01 and Imaemi-19, while H-Sand, I-Sand and J-Sand are suitable objectives between Imaemi-27 and Imaemi-02. Moreover, in-fill wells drilling locations can be selected to target H-Sand, M-Sand and N-Sand between Imaemi-33 and Imaemi-31 wells in the field.

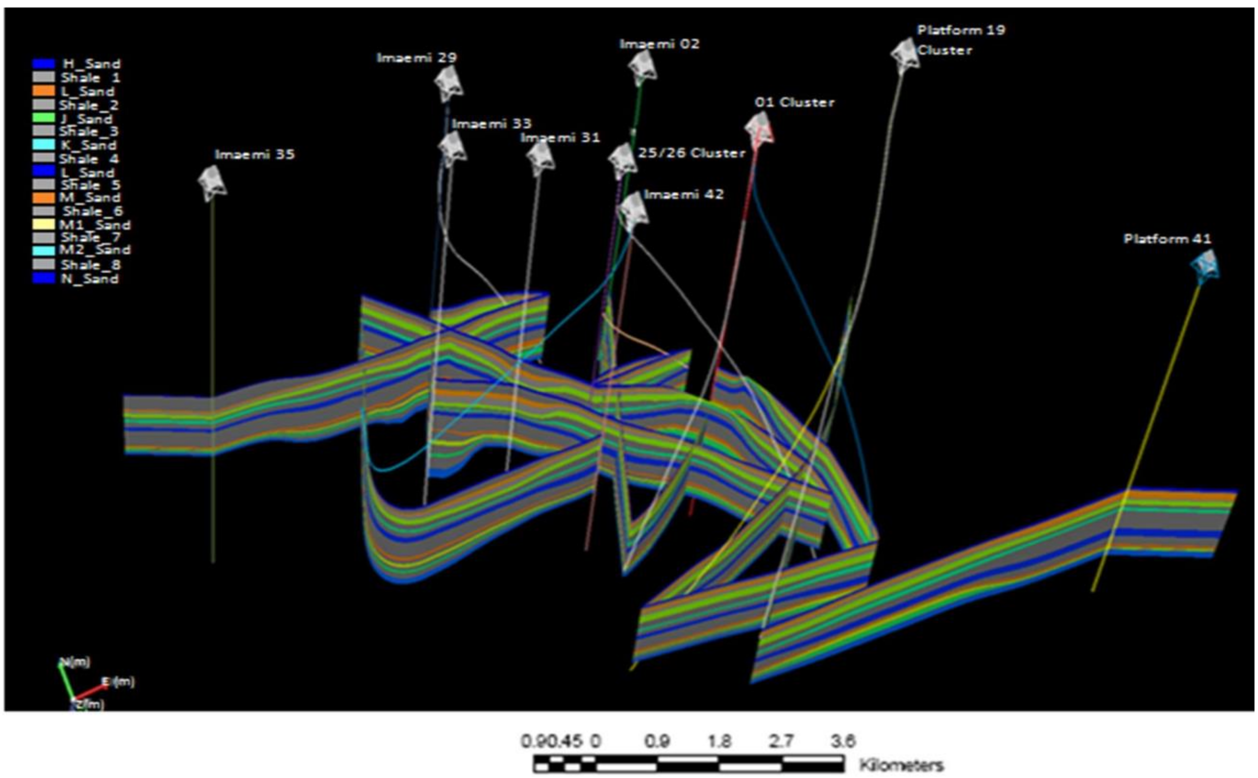

Figure 8. Stratigraphic Panel Diagram of Imaemi Field Showing Reservoirs Architecture from H-Sand to N-Sand, Viewing from the Southern Direction

8. Conclusion

It can be concluded that the application of the transgressive-regressive sequence stratigraphic technique in the study has led to the delineation of 11 Sequence Boundaries (SB-1 through to SB-11) which were correlated across the field, based on changes from prograding parasequence set to retrograding parasequence set stacking patterns. The reservoir architectural analysis yielded 24 vertically stacked, different reservoir bodies, informally named A-Sand through to Q-Sand, starting from the shallowest to the deepest. This approach eased reservoir location, correlation and characterization.

It is also possible to predict and target multiple reservoirs for appraisal and in-fill wells drilling through this approach. The geologic continuity of the H-Sand reservoir, including its hydrocarbon spatial distribution in the field, for instance, is predictable (Fig. 8). The H-Sand, I-Sand and N-Sand can be selected as in-fill wells objectives at locations between Imaemi-01 and Imaemi-19. The H-Sand, I-Sand and J-Sand are suitable objectives between Imaemi-27 and Imaemi-02, while H-Sand, M-Sand and N-Sand can be targeted between Imaemi-33 and Imaemi-31 wells in the field. Such development drilling could increase ultimate recovery from the field in case of future declining productivity.

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