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SEQUENCE STRATIGRAPHIC FRAMEWORK OF ALO AND IGBARIAM WELLS, ANAMBRA BASIN SOUTHEASTERN NIGERIA

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ABSTRACT

The sequence stratigraphic analysis of Alo and Igbariam wells in Anambra Basin was carried out to define the depositional systems in the study area. This research was based on the integration of wireline logs (gamma ray and resistivity) and biostratigraphic data. The results show that one maximum flooding surface (68.2Ma at 1845m) and two sequence boundaries (67.5Ma at 1560m and 68.89Ma at 2200m) were identified in Alo well while three maximum flooding surfaces (61.1Ma at 680m, 68.2Ma at 2620m and 69.14Ma at 3200m) and two sequence boundaries (67.5ma at 2520m and 68.89Ma at 2830m) were identified at Igbariam well. The depositional sequences as observed in both wells comprise of trangressive, lowstand, and highstand systems tract. The potential reservoirs identified in both wells were found in the lowstand systems tract which comprises of massive sand bodies believed to be the Ajali Formation. This is capped by thick shales which serve as seal. In both wells, Nkporo Formation was found at the base with Mamu Formation lying conformably at the top of it. This is in turn overlain by Ajali Sandstone which is covered by Nsukka Formation. At the topmost of the wells, Imo Shales were identified. The depositional environment of sand units A, B, C, D, E, F &G were found to be basin floor fan,distributary mouth bar,offshore bar,channel sand,turbidite channels or deltaic distributaries, alluvial sands, braided streams, fluvial channels or point bars, and tidal sands or fluvial channels respectively.

KEYWORDS: *Sequence boundary, Maximum flooding surface, Biofacies, Stacking pattern, Systems tract.*

1.0 INTRODUCTION

The stratigraphic aspects of the sedimentary sequences of Anambra basin, southern Nigeria have been studied by a number of workers like Kogbe (1989), Amajor (1984), Reyment (1965), Hoque and Ezepue (1977), Benerjee (1979) among others. There still exist unresolved debates about the possibility of hydrocarbon occurrence in this basin.

This study presents a local sequence stratigraphic analysis of Alo and Igbariam wells in Anambra basin and summarizes its implications for petroleum geology. Sequence stratigraphic analysis gives clear understanding of how stratigraphic units, facies tracts, and depositional elements relate to each other in time and space within a sedimentary basin (Catuneanu, 2006). The concept provides techniques for lithostratigraphic correlation of well logs, thereby yielding a more effective method for evaluating sandstone continuity and trend directions in reservoirs. It has also improved methods for predicting potential reservoir, source and sealing facies away from the well.

2.0 GEOLOGIC SETTING AND STRATIGRAPHY.

The study area is located in the southern part of Anambra Basin of Southern Nigeria as shown in figure 1 below.

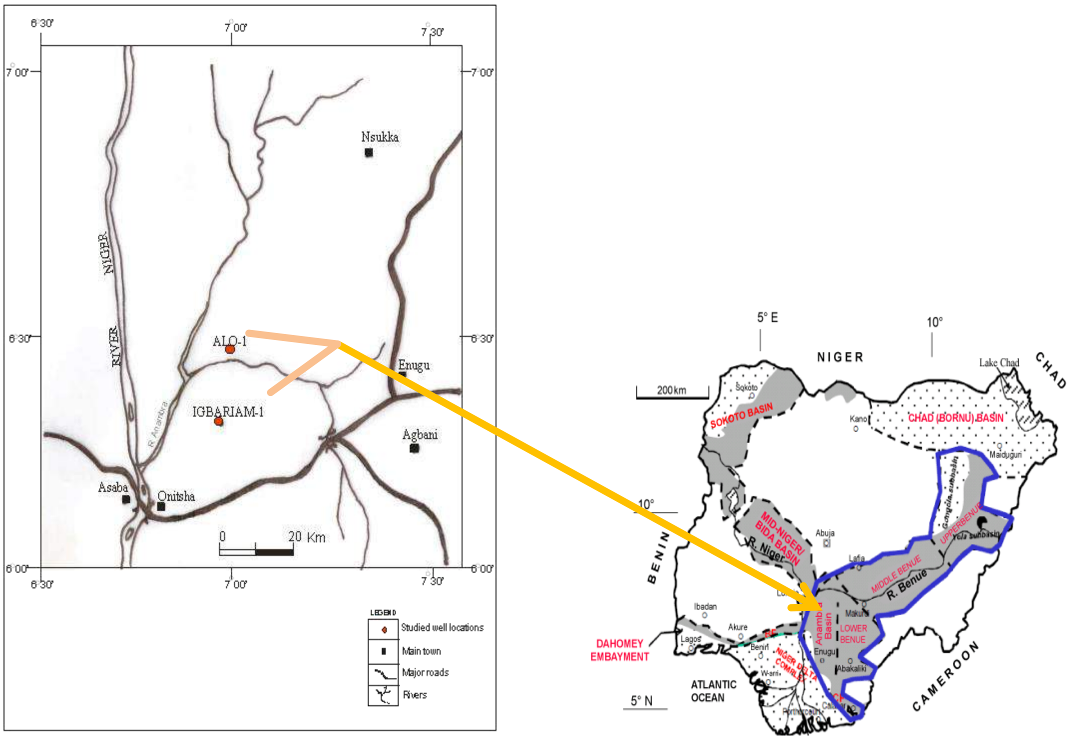

Figure 1: Location map of Anambra Basin showing the study area and the inset map of Nigeria (Nwajide, 2006)

The sediments of Anambra Basin include the Albian sediments which comprise of Asu River Group. These sediments contain alternating shales and siltstones with occurrences of sandstone. Asu River Group is the oldest stratigraphic unit in Anambra Basin. It is overlain by the Ezeaku Formation, which constitutes the Turonian deposits. Ezeaku Formation contains hard grey and black calcareous shale, limestone andsiltstone. This formation is covered by Awgu Shale which is predominantly shale. Awgu Shale was substituted by Agbani sandstones. The basal unit of Awgu Shale contains Turonian ammonites while the top is early Coniacian. Awgu Shale is superimposed by the paralic Nkporo/Enugu shale which has Owelli Sandstone as the lateral equivalent in the basin. Enugu Shale is pre-dominantly shales at the base with little limestone and sandstone occurrences. This formation is Coniacian-Santonian in age. The Mamu Formation covers the Nkporo shale. This formation is the basal unit of the coal measure sequence. It is a Campanian deposit. Mamu Formation consists of sandstones, carbonaceous shales, sandy shales and some coal seams. The Ajali Sandstone which is also known as false-bedded sandstone overlies the Mamu Formation. This formation is predominantly coarse grained sandstone. Ajali Sandstones are deposited during the Maastrichtian. The formation is superimposed by the last Cretaceous sediments in the basin which is the Nsukka Formation. This formation is also known as the Upper Coal Measures. It comprises of carbonaceous shales, sandstones and some thin coal seam. Overlying the Nsukka formation is the Imo Shale. The sediments of this formation consist of shales, shally-limestones and limestones. These sediments were deposited during the Paleocene (Kogbe, 1989). The Eocene Bende-Ameki Formationand its lateral equivalent (Nanka Sandstone)overlie the Imo Shale. On top of the Ameki formation is the Ogwashi-Asaba Formation which was deposited during the Oligo-Miocene Epoch. The Benin formation which is the last sediment inAnambra Basin was deposited above the Ogwashi-Asaba Formation. The formationis Pliocene-Recent in age. These formations are represented in their stratigraphic order as shown in Table 1.

Table1: Stratigraphic Succession in Anambra (Modified from Reyment, 1965)

AGE	FORMATION	
PLIOCENE - RECENT	BENIN FORMATION	
MIOCENE	OGWASHI-ASABA FORMATION	SB?
MID – LOWER EOCENE	NANKA/NSUGBE SANDSTONE	MFS ?
PALEOCENE	IMO SHALE/EBENEBE	(SB 65Ma)
MAASTRICHTIAN	NSUKKA FORMATION	
	AJALI SANDSTONE	
	MAMU FORMATION	
CAMPANIAN	ENUGU SHALE/OWELLI SANDSTONE	MFS ?
SANTONIAN		SB ?
CONIACIAN	AWGU SHALE/AGBANI SANDSTONE	MFS ?
TURONIAN	EZEAKU FORMATION NKALAGU LIMESTONE	
CENOMANIAN	ODUKPANI FM	SB ?
ALBIAN	ASU RIVER GROUP	MFS ?

SB = sequence boundary, MFS = maximum flooding surface

3.0 METHODOLOGY

3.1 Data Set:-

The data used for this study include; wireline logs, biostratigraphic data and Chronostratigraphic charts.

The wireline logs of the two wells comprise of gamma ray and resistivity logs.Biostratigraphic data includes biofacies data and foraminifera zone (F-Zone). The biofacies data provides information on total foraminifera abundance and diversity, total foraminifera planktonic abundance and diversity and also paleobathymetry.

The Cenozoic, Cretaceous, Jurassic and Triassic sequence Chronostratigraphic charts have information on the chronostratigraphy, relative age of systems, relative age of series, relative age of stages, sequence boundaries and maximum flooding surfaces.

3.2 FACIES IDENTIFICATION AND DEPOSITIONAL ENVIRONMENT

Facies were identified based upon the characteristic shapes and changes on the gamma ray log. Funnel shaped gamma ray log represents coarsening or cleaning upwards sequence and also decrease in clay contents. Bell shaped gamma ray log signature signifies Finning or dirtying upwards sequence and also increase in clay content. Finally, cylindrical shaped gamma ray denotes uniform bedding and consistent depositional energy within the bed. The environment of deposition was inferred from the integration of facies analysis with biofacies data.

3.3 RECOGNITION OF STACKING PATTERNS AND PARASEQUENCES

The facies stacking patterns and parasequences were recognized with the aid of well logs provided. The trends (coarsening or finning upward sequence) identified from well logs gave rise to progradational, retrogradational or aggradationalparasequences.

Retrogradational stacking (Fore-stepping) shows finning upward trend in gamma ray log. Progradational stacking (Back-stepping) displays coarsening upward trend, while aggradational stacking shows blocky trend (Figure 2).

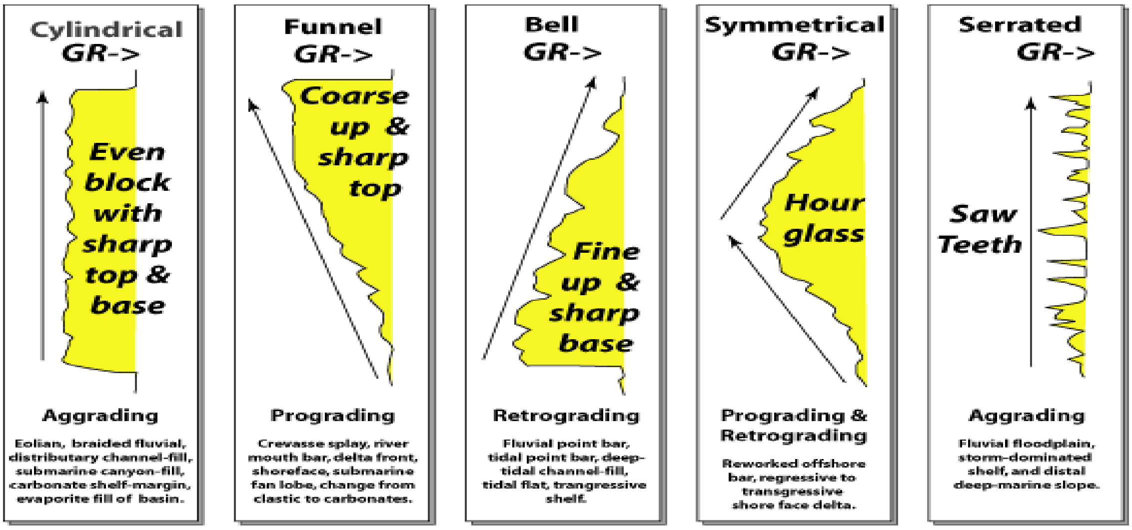

Figure 2: Gamma ray logs displaying various stacking patterns (After Emery and Myers, 1996).

3.4 KEY STRATIGRAPHIC SURFACES, SYSTEMS TRACT AND DEPOSITIONAL SEQUENCES

Maximum flooding surfaces were identified by the maximum shale peaks which correspond with zones of pelagic shales. Log readings display lowest resistivity and highest gamma ray values in this surface. These surfaces are associated with maximum foraminifera abundance and diversity. They fall on the boundary between retrogradational parasequence sets and progradational parasequence sets.

Sequence boundaries were recognized in areas where foraminifera abundance and diversity is very low or areas without bio-events which correspond to shallow section. They are also identified at the zone of high resistivity and low gamma ray readings. Sequence boundaries are common at the base of a progradational parasequences.

System tracts which comprise of lowstand system tracts, transgressive system tracts, and highstand system tracts were documented and mapped with the aid of the depositional model (Figure 3).

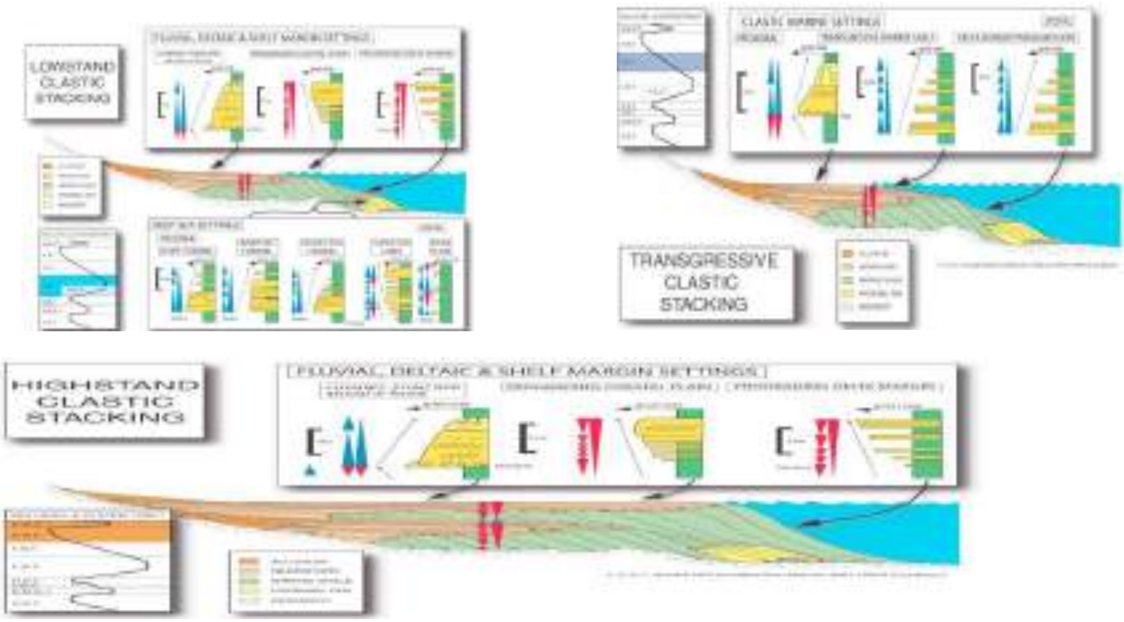

Figure 3: Lowstand, Transgressive and Highstand stacking patterns (After Kendall, 2004, based on Rider, 1999 and Baum x-section).

3.5 WELL CORRELATION

Well correlation involves associating the reservoir intervals from one well to the other. It determines the lateral continuity or discontinuity of facies.

The stratigraphic surfaces namely the maximum flooding surfaces and the sequence boundaries delineated in the study area were dated with Time stratigraphy and Microfloral zonation (Figure 4a) and further integrated with chronostratigraphic charts Figure 4b) so as to determine the relative ages of the surfaces. Finally, the two studied wells were correlated using the relative ages of the key surfaces.

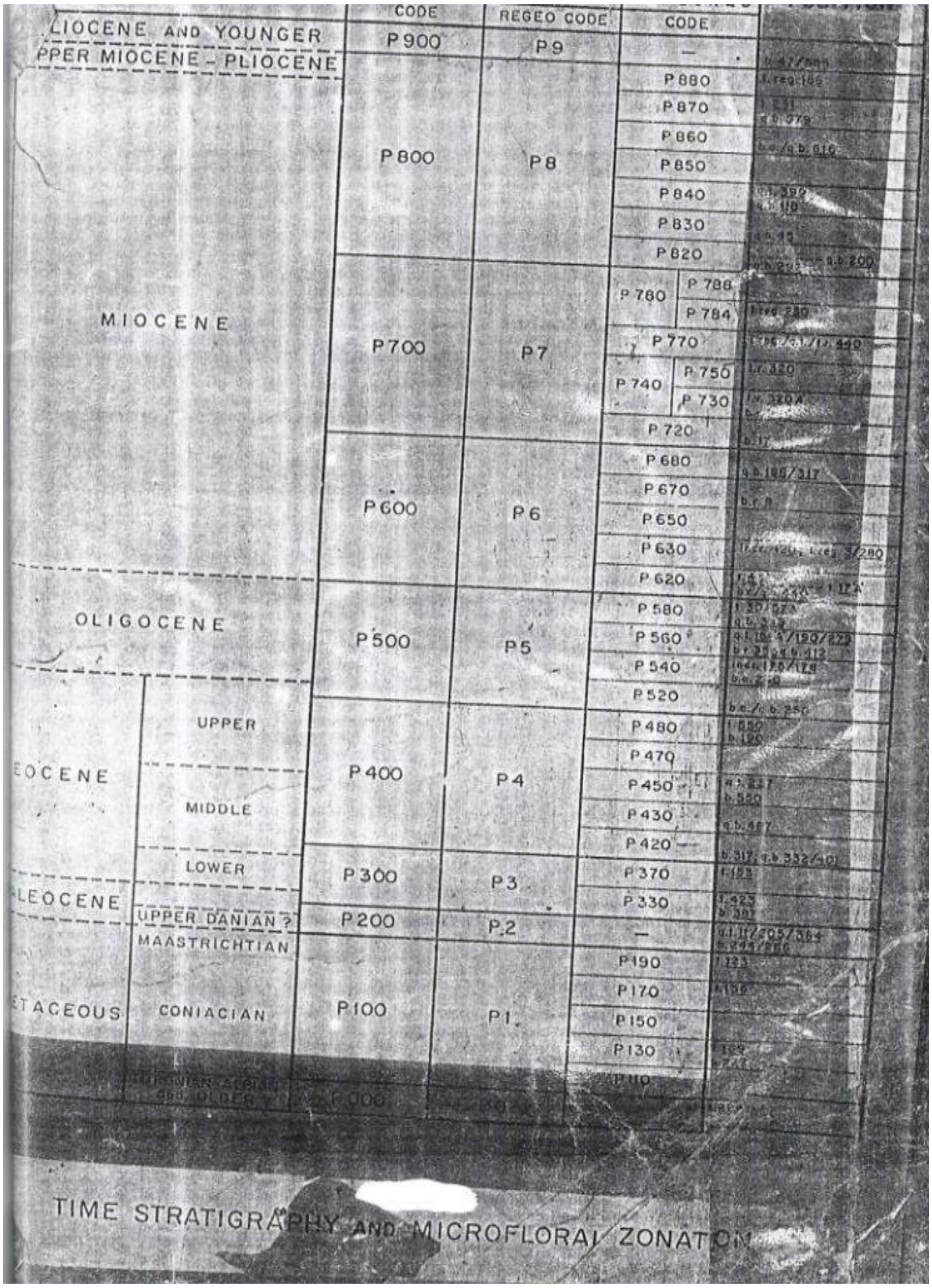

Figure 4a: Time Stratigraphy and Microfloral zonations

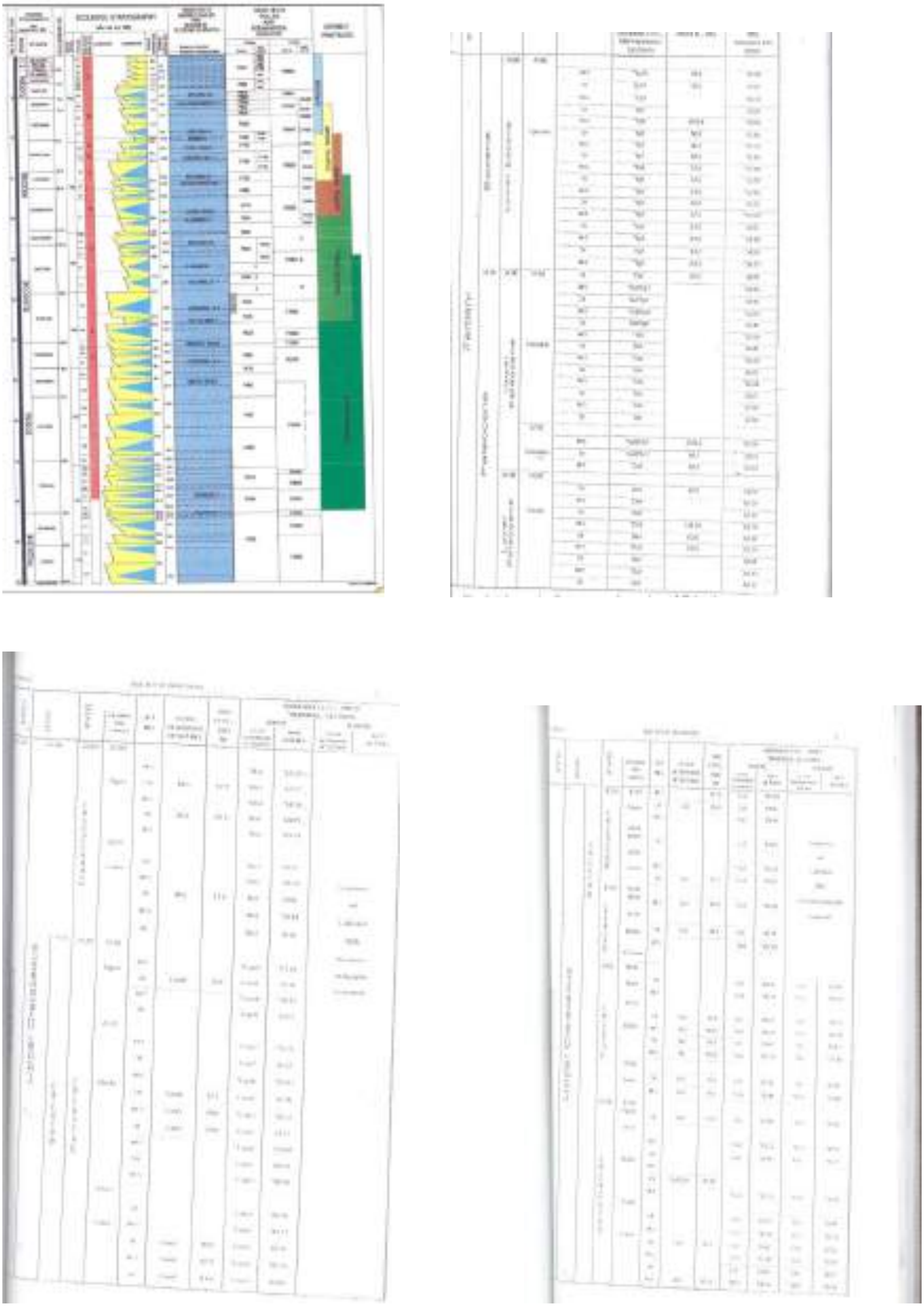

Figure 4b: The Cenozoic, Cretaceous, Jurassic and Triassic sequence Chronostratigraphic charts.

4.0 RESULTS AND DISCUSSION

4.1 FACIES IDENTIFICATION AND DEPOSITIONAL ENVIRONMENT

Results from well logs have shown that Sandstone, siltstone and shale are the major lithologic units common in the study area. The interval coloured yellow depicts sandstone, siltstone's interval is represented in green colour while the interval coloured black signifies shale (Figure 5).

Seven facies labelled A to G were documented in both wells.

Facies A

A cylindrical-shaped succession was observed between depths 660 – 1150m. This blocky cylindrical shaped facies has sharp boundaries and is within marine paleobathymetry.The environment of deposition may be interpreted as basin floor fan based on facies motif and paleobathymetric setting.

Facies B

Funnel-shaped succession as documented in facies B has a sharp basal contact.

The gamma ray log signature is spiky and coarsening upward. It was encountered at a depth range of 1260–1330m. Facies B is within non- marine paleobathymetry

The paleoenvironmentis inferred as distributary mouth bar.

Facies C

This sand unit shows a blocky log signature which is coarsening upward. It occurs between depths 1520 – 1550m. The basal contact is gradational. Facies C is within Neritic paleobathymetry. This facies can be said to represent offshore bar.

Facies D

The log signature of facies D displays blocky and dirtying upward sequence. The depth of this sand body falls within 2170 – 2220m. The basal contact is sharp and is withinnon-marine setting. Based on the gamma ray log characteristics and paleobathymetry, this facies may be interpreted as channel sand.

Facies E

This facies falls within a depth range of 1100 – 1500m. The basal and upper contact of this sand unit is sharp with serrated blocky log signature which is cylindrical in shape. This facies may represent turbidite channels or deltaic distributaries since the upper unit of the facies falls within Middle Neritic and the lower section, non-marine.

Facies F

This bell shaped facies shows a dirtying upward sequence with a sharp upper

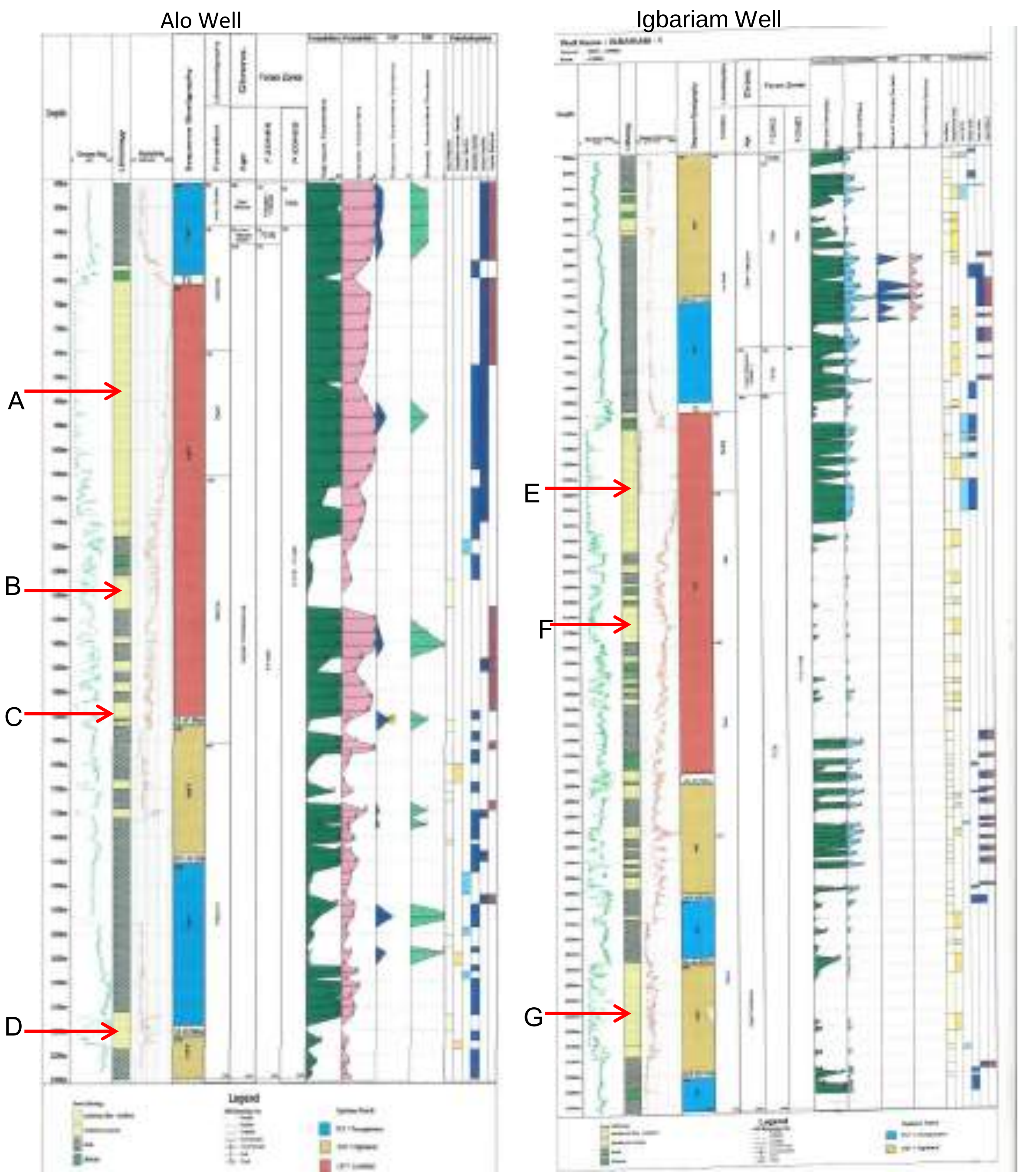

Figure 5: Sequence Stratigraphic interpretation of Alo and Igbariam wells.

contact while the basal contact is gradational. The depth range is about 1660–1790m. It occurs within non-marine setting. The environment of deposition may be interpreted as alluvial sands, braided streams, fluvial channels or point bars.

Facies G

The cylindrical shaped facies with depth range of 2850 – 3140m is found within non- marine paleobathymetry. It is blocky and also has a sharp basal contact.Based on well logs analysis and paleobathymetric setting, the environment of deposition may be inferred as tidal sands or fluvial channels.

4.2 RECOGNITION OF STACKING PATTERNS AND PARASEQUENCES

Figure 6below shows one dimensional stratigraphic interpretation displaying stacking patterns of progradation and retrogradation in the sequences and parasequences for the studied wells.

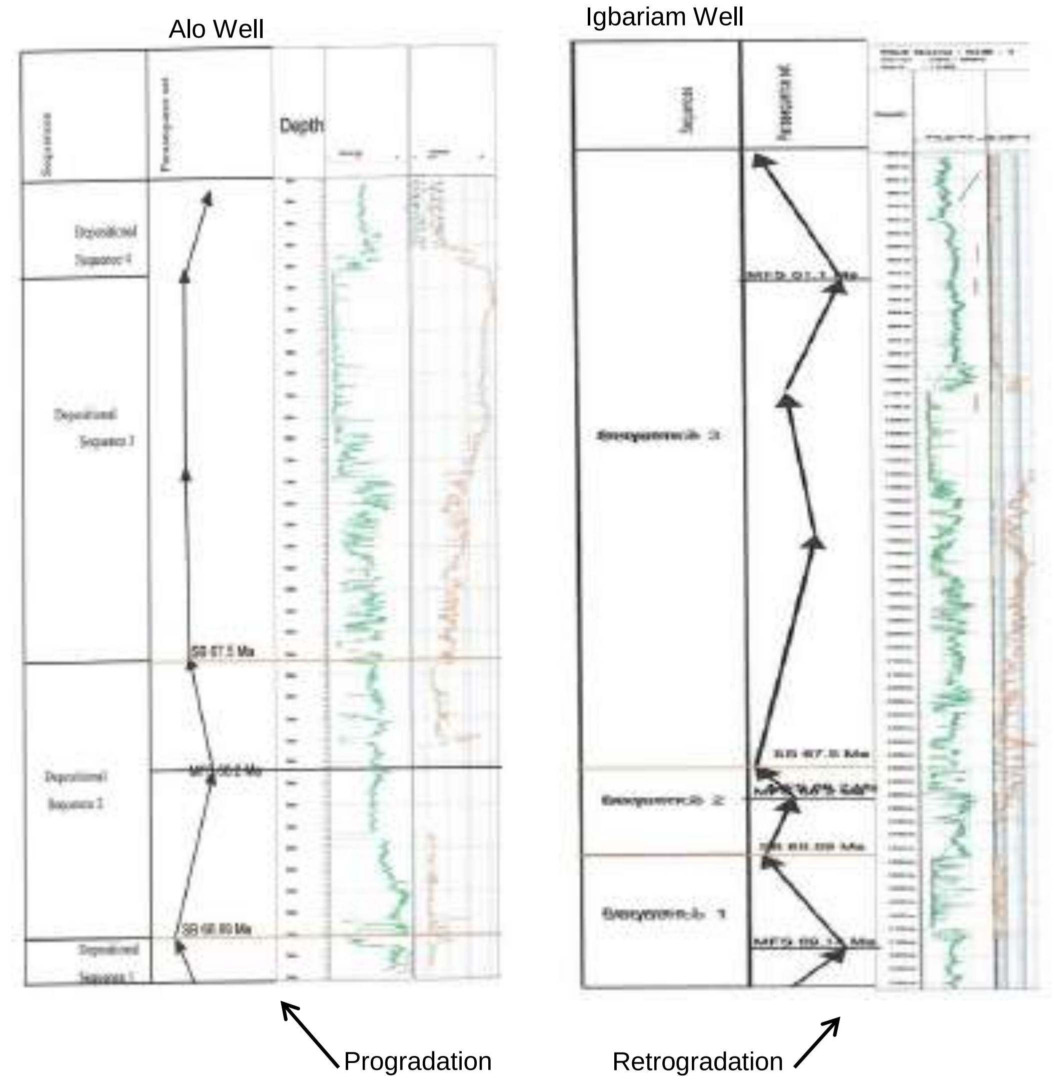

Figure 6: One-dimensional stratigraphic interpretation showing vertical stacking pattern of progradation and retrogradation in sequences.

4.3 KEY STRATIGRAPHIC SURFACES, SYSTEM TRACTS AND DEPOSITIONAL SEQUENCES

4.3.1 Key stratigraphic surfaces

A total of four maximum flooding surfaces were identified in both wells. One maximum flooding surface was observed in Alo well (68.2Ma at 1845m) while three maximum flooding surfaces were identified at Igbariam well (61.1Ma at 680m, 68.2Ma at 2620m and 69.14Ma at 3200m). Four sequence boundaries, two at each well were identified. In Alo well, the sequence boundaries occurred in 67.5Ma at 1560m and 68.89Ma at 2200m while at Igbariam well, the sequence boundaries were documented in 67.5Ma at 2520m, and 68.89Ma at 2830m. Table 2.0 shows the depths and ages of the maximum flooding surfaces and sequence boundaries in the studied wells.

Table 2.0: Depths and ages of the maximum flooding surfaces (MFS) and sequence boundaries (SB) in studied wells

Stratigraphic surfaces	Ages (Ma)	DEPTH (M)	
		Alo	Igbariam
MFS	61.1		680
SB	67.5	1560	2520
MFS	68.2	1845	2620
SB	68.89	2200	2830
MFS	69.14		3200

Again, at the base of both wells, shales, thin beds of sandy shales and sandstones were encountered. This unit can be said to be Nkporo Formation based on the geologic age (Figure 4). Overlain by this, is Mamu Formation which consists of shales, sandy shales and this is followed by Ajali Sandstone which is predominantly sandstone. Ajali Formation is covered by the Nsukka Formation which is apparently the last Cretaceous sediments as observed in both wells. At the topmost of the wells is the Imo Formation which has thick shale bodies.

4.3.2 System tracts

The three systems tract namely the transgressive systems tract (TST), the highstand systems tract (HST), and lowstand systems tract (LST) were represented in the studied wells.

Transgressive systems tract (TST)

The transgressive systems tract is interpreted to form during the maximum rate of relative rise in sea level. In Alo well (1340-1560m) and Igbariam well (2100-2520m) are sand bodies characterized by upward fining log motifs within the transgressive systems tract. Well log patterns of the transgressive systemstract withinneriticenvironment in both wells are characterized by a set of parasequences each ofwhich is finer grained than the underlying one.

Highstand Systems Tract (HST)

The rate of sea level rise decreases during the development of highstand systems tract (Vail 1987). Well logs pattern in highstand systems tract are characterized by intervals of coarsening upwards parasequence stacking pattern that are predominantly for estepping or building basinward laterally into neritic shales. In the studied wells, the highstand systems tract is thicker in Igbariam well than in Alo well. The highstand systems tract has been identified nearly in all the intervals.

Lowstand Systems Tract (LST)

Lowstand systems tract were recognized in the studied wells. It was identified in Alo well at the depth range of 660-1150m while at Igbariam well, it was observed at the depth of 1050-2220m.The thickness of lowstand systems tract observed in Alo well is greater than that observed at Igbariam well.

4.3.3 Depositional sequences

A total of three sequences were identified as shown on Figure 5 above. They are as follows:

Sequence 1

This sequence starts with sandy shale unit which changes to aggradational unit in the upper part of Igbariam well. The progradational unit in this well is truncated by a maximum flooding surface (MFS; 69.14Ma) and is defined at the point of change in the stacking pattern from a net fining upward to a net coarsening upward. The
highstand systems tract in Alo well (370m is less in thickness than its equivalent in Igbariam well because the sequence was not fully penetrated.

Sequence II

This sequence is predominantly shale with sand intercalation in both wells. The highstand systems tracts (HST; 2520-2620m) are mainly sandy shale. The transgressive systems tract is predominantly shale sequence with the major sand body in an overall retrogradational stacking pattern towards the maximum flooding surface (MFS 68.2Ma) which fines upwards into overlying sandy shale. The transgressive systems tract (TST) in Alo well is of greater thickness (355m) than that of

Igbariam well (210m) but the transgressive sand body in Igbariam well has a greater thickness than that of Alo well.

Sequence III

Sequence III is comparatively the largest sequence in both wells with thickness of 1110m and 2320m in Alo and Igbariam wells respectively. The transgressive systems tract (TST) in both wells consists of sandy shale. The lowstand systems tract (LST) is mainly sandy shale at the base with massive sandy body at the top. These thick sandy bodies were identified as the potential reservoir bodies in both wells. The thickness of the sand bodies is greater in Alo well (450m) than in Igbariam well (330m). These massive sand bodies observed are overlain by shales which serve as seal for the potential reservoir bodies. From the geology of Anambra basin, the potential reservoirs can be said to be Ajali Sandstone partly because of their deposition during upper Cretaceous and they constitute mainly sandstone.

Crescentic shaped log pattern has been observed in the middle part of the lowstand systems tract in Igbariam well. Above the lowstand systems tract is the trangressive systems tract which was identified at the top of Alo well, while at Igbariam well the highstand systems tract is found on top of the well. The uppermost part of this sequence is predominantly shale.

4.3.4 Correlation of Key Stratigraphic Surface

The stratigraphic surfaces namely the maximum flooding surfaces and the sequence boundaries were correlated across the wells (Figure 7). This was done to determine the lateral continuity of the sand bodies.

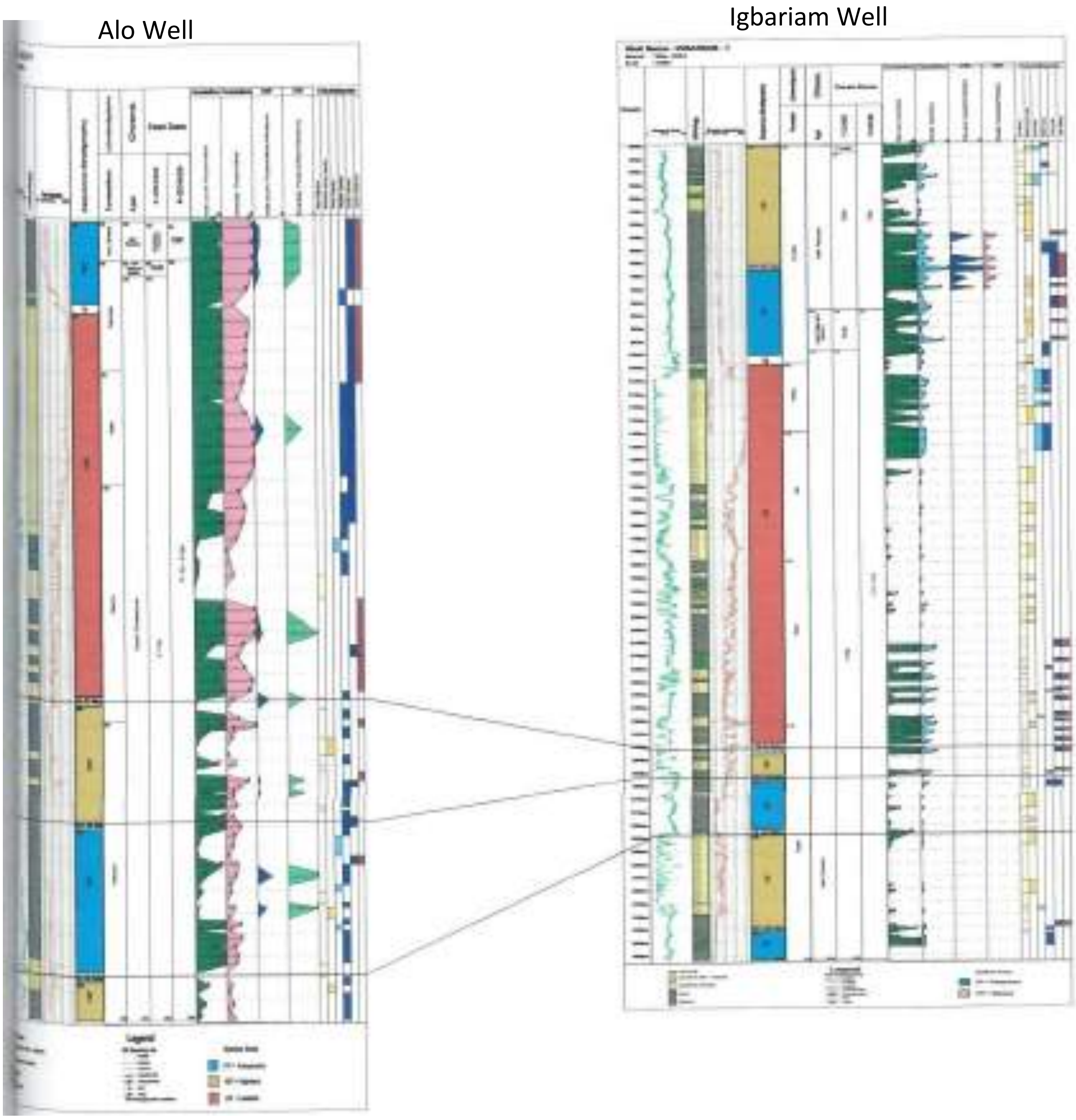

Figure 7: Correlation of Igbariam and Alo wells in Anambra Basin.

SUMMARY AND CONCLUSIONS

The sequence stratigraphic interpretation of the upper Cretaceous – Paleocene sediments in Anambra basin has been conducted using wireline log and biostratigraphic data. Field correlation of the studied wells gave insight into the depositional history of the studied area highlighting major unconformities. Four maximum flooding surfaces define three depositional sequences. The depositional sequences were subdivided into systems tract. All the three systems tract namely the transgressive systems tract (TST), the highstand systems tract (HST), and lowstand systems tracts (LST) were represented in the studied wells, though at varying thickness.

The relative thickness of the systems tract reveal changes in sediment accumulation rate as a result of changing local condition including availability of accommodation space, effects of gravity tectonics and regional and eustatic changes in sea level. Potential reservoirs believed to be Ajali Formation were found in both wells with the thicker reservoir in Alo well. These are capped with shales which serve as seal. The Upper Cretaceous sequences as observed in these wells are thicker than Paleocene sequences. The depositional environments of the sand units A,B,C,D,E,F and G arebasin floor fan,distributary mouth bar, offshore bar, channel sand, turbidite channels or deltaic distributaries, alluvial sands, braided streams, fluvial channels or point bars, and tidal sands or fluvial channels.

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