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Well-Log Sequence Stratigraphy and Paleobathymetry of Well -X, Offshore Western Niger Delta, Nigeria

[1]*A.O. Ola-Buraimo*, [2]*J.E. Ogala and* [3]*O.F. Adebayo*

[1]Department of Earth Sciences, Ladoke Akintola University of Technology, Ogbomoso, Nigeria
[2]Department of Geology, Delta State University, Abraka, Nigeria
[3]Department of Geology, University of Ado-Ekiti, Nigeria

Abstract: Composite well-logs and ditch cuttings were employed for the interpretation of sequence stratigraphy and paleobathymetry of Well-X in the offshore western Niger Delta in order to characterize the analyzed intervals into genetic segments and to differentiate maximum flooding surface (MFS) in shale sequences of high radioactive elements and upper shoreface sands in shallow environment and lower shoreface facies in deep water setting. Three sequences were recognized and divided into systems tracts. The basal systems tracts of sequence one is a lowstand system tract (LST) of a slope fan complex, associated with channel overbanks 1, 2, 3 and 4 (5160-5790ft). The sequence one is overlain at the surface by a highstand systems tract (TST) marked by a basal maximum flooding surface placed at 4885ft. The sequence two is deposited on a continental high within a lower shoreface setting and is characterized at the base by lowstand systems tract prograding complex (LSTPC) with a condensed section at 4480-4460ft. Within the LSTPC, a sequence boundary (SB) was identified by the stacking patterns between MFS surfaces. The SB is placed at 4390ft. Transgressive systems tract surface (TST) identified at depth 4080ft is marked by a MFS which characterize both the top of the TST and base of highstand systems tract (HST) of the sequence two. Sequence three is only associated with transgressive systems tract (3200-3890ft). The top of the HST is marked by MFS at depth 3240ft and the interval is characterized by upward deepening from upper shoreface at the base to probably middle shoreface at the top. Paleobathymetry interpretation permitted the identification of rock facies which vary from sand, through shale and heterolith component to hemipelagic shale of turbidite deposits. The paleoenvironment of deposition is characterized by upper bathyal at the base through lower and upper shoreface settings to middle shoreface at the top of the analyzed interval.

Key words: Sequence stratigraphy · Systems tracts · Shoreface · Neritic · Channel fill

INTRODUCTION

Well-log sequence stratigraphy is an integral part of well-log seismic sequence stratigraphy which encompasses the application of three different tools: well-log, seismic and biostratigraphic study. In this study, attempts are made to combine well log with detailed lithologic description from ditch cuttings. This method permits geologists to divide a rock section into series of genetic units bounded by condensed section and their associated maximum flooding surface using wire line log signatures. Each sequence bounded by maximum flooding surface (MFS) is sub-divided into smaller sediment packages called systems tracts on the basis of characteristic well-log patterns [1]. Rock types in relation to depositional environments and systems tracts were made possible by identification of specific gamma ray pattern and combined log patterns of both neutron and density logs.

Maximum flooding surface and its associated depositional facies, condensed section were identified through the use of neutron-density log pattern by locating the point of maximum separation between the neutron and density porosities. This point also corresponds to the lowest shale resistivity or high resistivity shale that is highly fossiliferous and calcareous in nature. In this paper, [2] method was adopted as a more appropriate step towards a starting point for predictive stratigraphic interpretation in Niger Delta (Figure 1).

Corresponding Author: J.E. Ogala, Department of Geology, Delta State University, Abraka, Nigeria.
Tel: +234-803-325-7855, E-mail: etunimogala@yahoo.com.

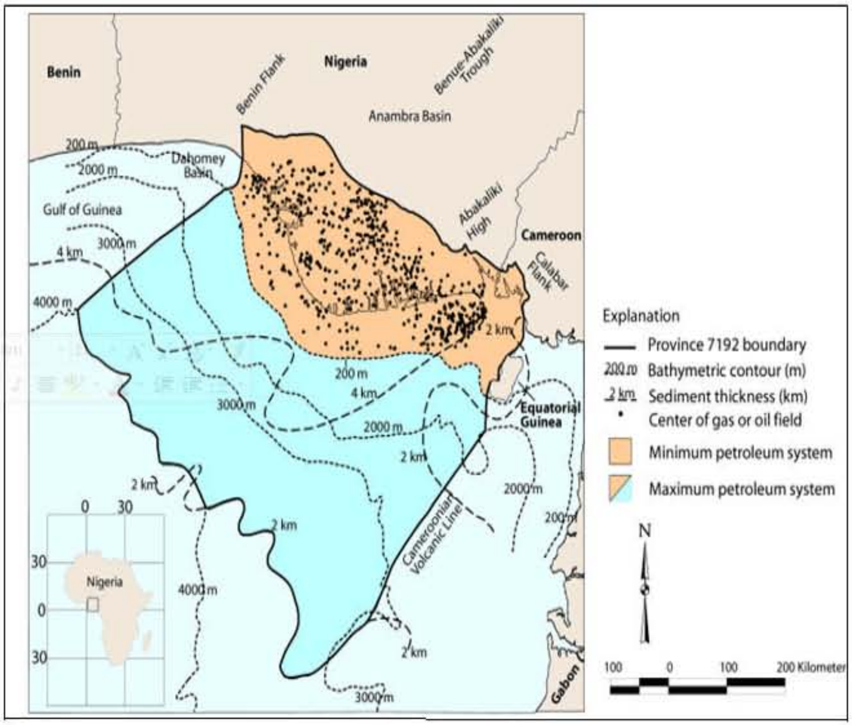

Fig. 1: Map of Niger Delta showing province outl;ine (maximum petroleum system); bounding structural feature; minimum petroleum system as defined by oil and gas field center points

Data Requirement: For this study two types of data sets were used; well-logs and ditch cutting samples necessary for lithologic description. However, a full suites of petrophysically corrected wire-line logs that consists of gamma ray, resistivity, neutron and density logs and caliper log if available are appropriate for use.

MATERIALS AND METHODS

The concept is based on the assumption that sea level changes are the predominant control on stratigraphic architecture, geometries and facies, but recognizes that rate of sedimentation; tectonic, subsidence, isostasy and compaction contribute to creating space for sediment accommodation [3]. Therefore, sequence stratigraphy is a hierarchical system in which genetic units and elements are correctly placed in a high resolution framework of time lines.

A sequence is defined as a relatively conformable, genetically related succession of strata bounded by unconformities or their correlative conformities [4]. Parasequences and parasequence sets are the building blocks of sequences. Thus, parasequences comprise of a relatively conformable, genetically related succession of beds or bed sets bounded by marine flooding surfaces that mark an increase in water depth resulting from a change in relative sea level. Parasequence sets are identified and defined to comprise of succession of genetically related parasequences that form a distinctive stacking pattern such as progradational, aggradational or retrogradational, usually bounded by major marine flooding surfaces [5]. Subsequently, each sequence is subdivided into smaller sedimentary packages called systems tracts on the basis of characteristic well log patterns.

The technique adopted in identifying which shale contains the maximum flooding surfaces is the use of neutron – density log. Flooding surfaces within marine shale are identified by locating the point of maximum separation between the neutron and density porosities. This point also corresponds to the lowest shale resistivity values relative to the surrounding flooding surfaces and high gamma ray value.

Sequence boundaries were identified by analyzing stacking patterns between maximum flooding surfaces. Therefore, an upward-increasing flooding surface resistivity trend and upward-decreasing flooding surface neutron porosity correspond to forward-stepping (prograding) of delta cycles (Figure 2); while trends of decreasing flooding surface resistivity and increasing

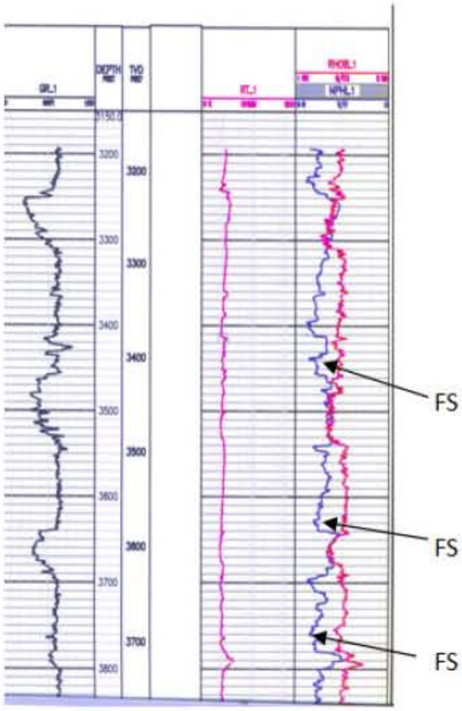

Fig. 2: Upward increasing flooding surface and decreasing resistivity; prograding delta (3770-3300 ft).

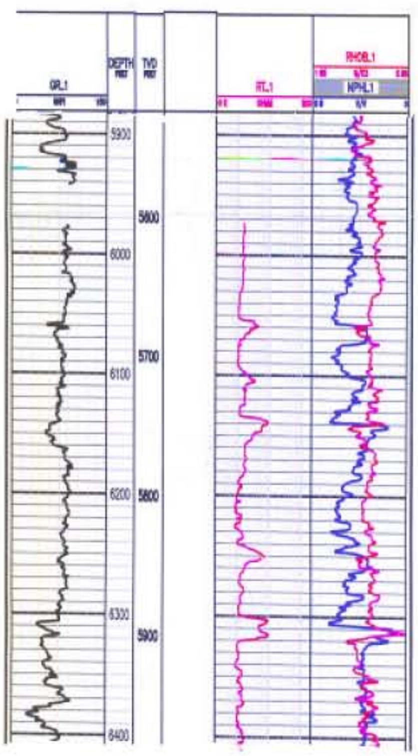

Fig. 3: Trend of decrasing resistivity and increasing flooding surface neutron porosity; retrogradation

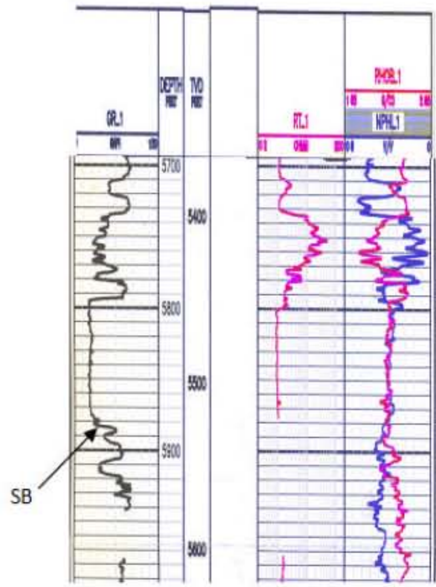

Fig. 4a: Location of sequence boundary (SB) 5885 ft.

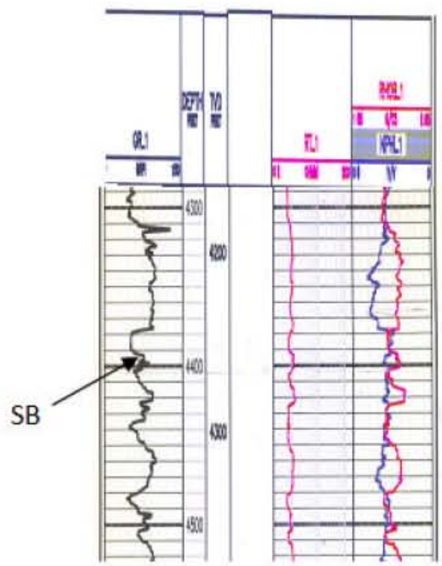

Fig. 4b: Sequence boundary (SB) placed at 4390 ft.

flooding surface neutron porosity corresponds to backstepping (retrogradation) of the delta, or transgressive phase of the marine water incursion (Figure 3). This two stacking patterns are separated by a surface which contains the time of maximum basinward shift of the shoreline position within the cycle and thus defines the position of the sequence boundary (SB) (Figure 4). The sequence boundary is further characterized by low gamma ray values, high resistivity and change in the direction of cross-plot of neutron and porosity log signatures.

In this paper, the genetic stratigraphic sequence approach in basin analysis, architecture and genesis of flooding-surface bounded depositional units is adopted as a more appropriate step towards a starting point for predictive stratigraphic interpretation in Niger Delta (Figure 1). This method defines a genetic sequence as that between two maximum flooding surfaces. This paper is geared towards helping young geologists in the industry and particularly students of geology in the university to understand the application of this tool with the view to increasing the hydrocarbon exploration.

RESULT AND DISCUSSION

The stratigraphic interval of well-x studied from the Niger Delta ranges in depth from 3200ft to 5790ft. Stratigraphic sequences are subdivided into smaller sedimentary packages called systems tracts. Such systems tracts include lowstand systems tract (LST), transgressive systems tract (TST) and highstand systems tract (HST). The MFS was first established, thereby dividing the entire sedimentary stratigraphy under consideration (5790-3200ft) into sequences. In this study, three sedimentary sequences were established.

Sequence one (5790-4480ft) is composed of the three main systems tracts: lowstand systems tract (LST), transgressive systems tract (TST) and highstand systems tract (HST). The LST is located at the base of sequence one. The LST has depth range from 5790ft at the base of the log where the analysis commenced and the top is placed at 5160ft. The base of the interval is characterized by flooding surface associated with high gamma ray value, low resistivity and moderately separated neutron and density log pattern compared to the overlying and underlying beds. The top of the LST is marked by a flooding surface (FS). The interval is characterized by channel overbank deposits 1, 2, 3 and 4 associated with lowstand slope fan complex (Figure 5). Within the channel/overbank units are identified abandoned facies (AF), channel fill (CF), internal channel erosional surface (ICES) and basal channel erosional surface (BCES). Others are attached lobes (AL), overbank (OB) and Apron (A) units. The channel/overbank units are crescent shaped and within them sand thickens, then thin upward. The channel fill facies may be massive turbidite sands fining upward with sharp bases (Figure 7). The top of the LST is a downward shift from hemipelagic shale, overlying it is laminated fine grain turbidites. The base of the LST (5790ft) is associated with minor condensed section of hemipelagic shale.

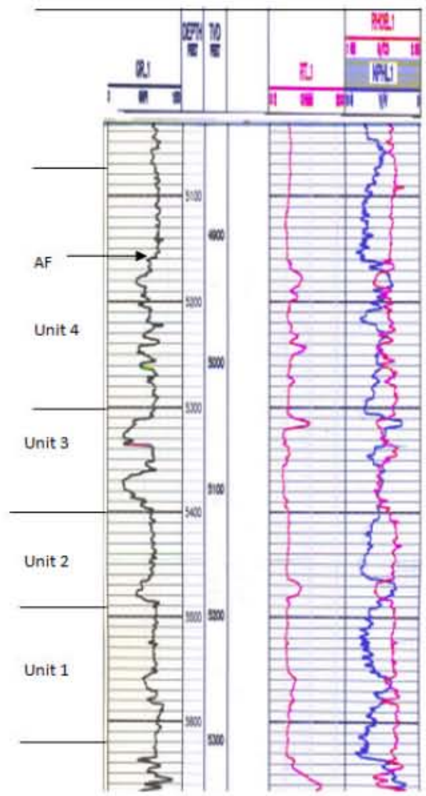

Fig. 5: Section showing channel overbank units 1, 2, 3 and 4 within a lowstand system tract (LST) 5300-5600 ft.

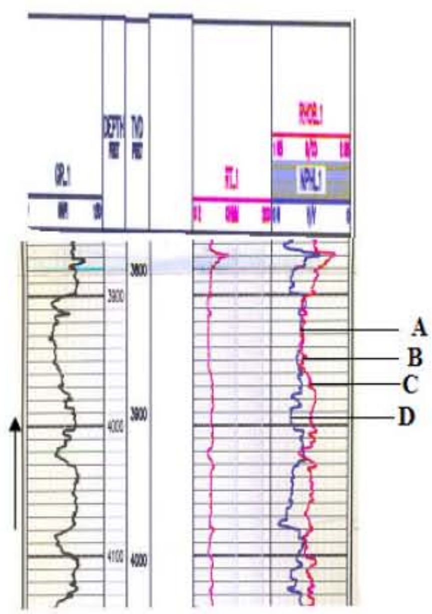

Fig. 6: Upper shoreface to open marine clay deposit and paleobathymetry (3900-4080 ft.); A: Channel; B: Upper shoreface; C: Lower shoreface and D: Open marine

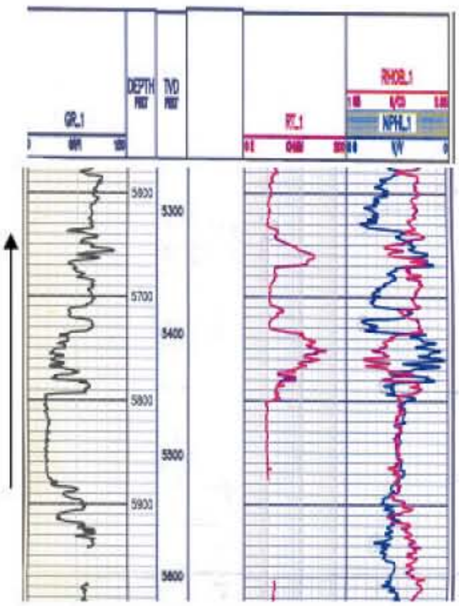

Fig. 7: Channel fill facies, characterized by blocky shaped, sharp base and fining upward turbidit sand (5600-5880 ft.)

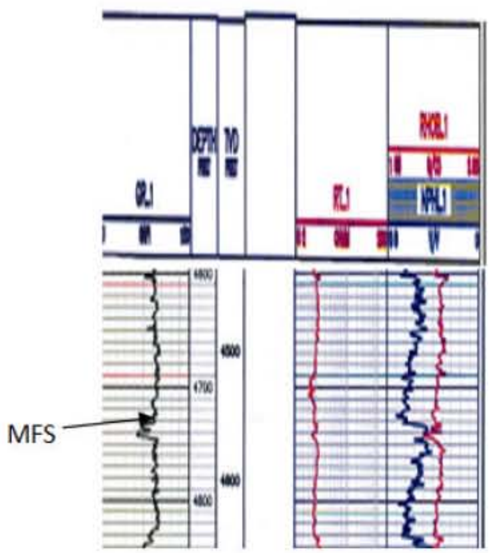

Fig. 8: Transgressive system tract associated with condensed section (4690-4710 ft.) and maximum flooding surface (MFS)

The Transgressive systems tract (TST) with interval 5160-4885ft overlies the thickly bedded lowstand systems tract of the slope fan complex. The TST is marked at the top (4700ft) by the identification of maximum flooding surface (MFS) and condenced section (CS-4710-4690ft) associated with high gamma ray, high resistivity value suggestive of a possible source rock and highly fossiliferous of calcareous fossils [6].

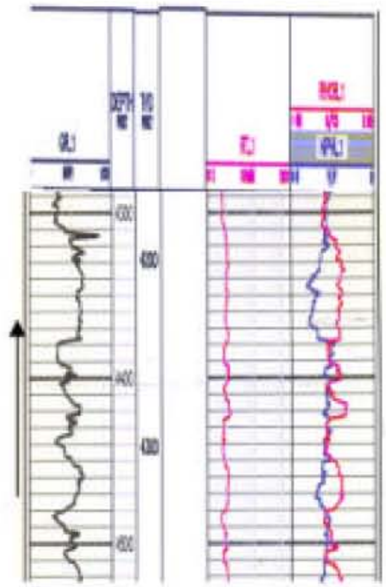

Fig. 9: Lowstand prograding complex (4365-4480 ft.)

It is as well characterized by a wide separation of the neutron and density logs (Figure 8). The base is defined by flooding surface, hemipelagic in nature shifting downward into turbidite sand.

Highstand systems tract of interval 4700-4480ft marks the top of sequence one. The top of the interval at 4480ft is marked by a condensed section (4480-4460) rich in organic matter. It is characterized by high gamma ray value, high resistivity range value (highly fossiliferous of calcareous fossils) and wide separation of neutron and density log signatures. The interval is further characterized by coarsening and shallowing upward sequence of intercalated thick shale and thin sandstone units. The paleo-bathymetry of the entire sequence one is quite deep at the base. Sediments were deposited in the upper bathyal and become shallower at the near top into probably outer- neritc zone.

Sequence two (4480-3890ft) lies conformably on sequence one. The base of sequence two (4480ft) coincides with the top of sequence one. Lower part of this stratigraphic interval (4480-4365ft) is characterized by LST prograding complex (Figure 9). The top is defined by flooding surface characterized by high gamma ray value, high resistivity value and wide separation of neutron and density log signatures. The top is also a transition from upward shallowing to upward deepening into overlying TST. The interval is characterized by upward coarsening sands deposited in the shoreface but grades into deeper bathyal hemipelagic shale. Within the LST prograding complex (LSTPC) is the identification

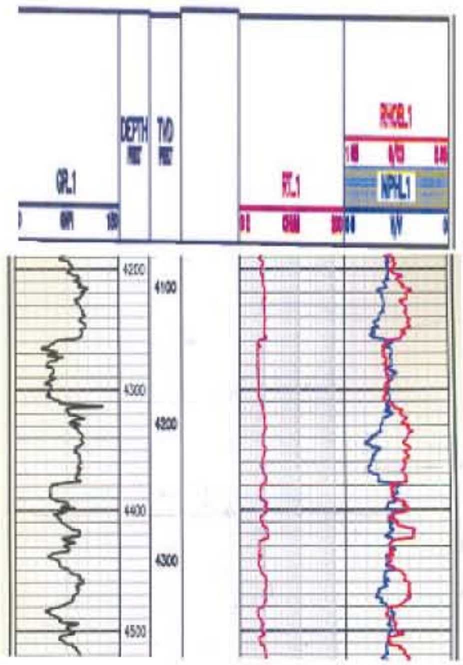

Fig. 10: Stacked and cyclic sedimentary packagee.

of sequence boundary placed at 4390ft (Figure 4b). The SB was identified by analyzing stacking patterns between maximum flooding surfaces. Here, trends of upward-increasing flooding surface resistivity and upward-decreasing flooding surface neutron porosity corresponds to forward-stepping (progradation of delta cycles (Figure 2). However, at any other instance where we have contrast trends of decreasing flooding surface resistivity and increasing flooding surface neutron porosity, it corresponds to a back-stepping (retrogradation) of the delta (Figure 3). Thus, the two stacking patterns are separated by a surface which contains the time of maximum basinward shift of the shoreline position within the cycle referred to as the position of the sequence boundary (SB).

Trangressive systems tract (4365-4080ft) overlies the LSTPC. The TST is wedge-like in nature because it is cyclical in term of sediment packaging pattern (Fig. 10). The top of the interval placed at 4080ft is marked by a maximum flooding surface (MFS) defined by high gamma ray value, low resistivity and relatively wide gap between neutron and density log signatures compared to its surrounding. The MFS indicate maximum shoreline shift into the continent during transgression [7-8].

Highstand systems tract (HST) located at 4080-3890ft overlie the TST. The top of the interval is characterized by FS. There are sediment aggradations and the interval shows coarsening and shallowing upward sand and shale

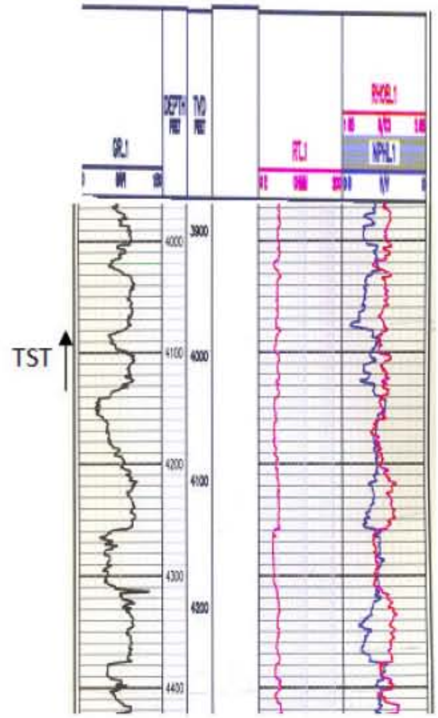

Fig. 11: Aggradation/TST wedge sediments (4080-4365 ft.)

interbeds (Figure 11). The paleobathymetry of sequence two varies from outer-neritic at the base to upper shoreface at the top (Figure 6).

In actual fact, sedimentary processes led to different sediment characteristics. Therefore, these genetic characters are seen in their peculiar log patterns. For channel deposits that are usually closely associated with LST, the log response usually shows blocky shape with a clear sharp base. The channel sands are also characterized by little or no separation between the neutron and density porosity log signatures. Sometimes, they are similar to upper shoreface log response, but commonly the channels display lower apparent neutron and density porosities than upper shoreface facies as a result of difference in sorting property. The channel sand is poorly sorted while the upper shoreface sediments are well sorted due to high current energy action that winnows the sand grain particles forth and back by multidirectional current.

The upper shoreface facies share the same log response with channel elements (Figure 6). They are as well defined by low gamma ray values which indicate clean sand. They can further be differentiated from channels by their close association with the underlying lower shoreface elements of the same prograding unit (Figure 6).

The lower shoreface is interpreted in this well by the patterns shown which depict a gradual coarsening upward of prograding shoreface deposits from marine shale to lower shoreface sands that clearly reflect a bell- shaped neutron – density log separation pattern (Figure 6) Therefore, the integration of combined suite of well-logs and sediment properties achieved from lithological description has helped tremendously in distinguishing different sediment genetics in relation to their paleobathymetric setting in Niger Delta, Nigeria.

CONCLUSION

Detailed well-log sequence stratigraphy of the well-x in offshore western Niger Delta was made possible by the use of complete suite of logs combined with adequate lithologic description. Sedimentary packages delineation in term of systems tracts was achieved by first identifying the maximum flooding surfaces present in the well-section. The common error or difficulty in differentiating maximum flooding surface associated with marine shales and radioactive elements present in both shallow upper shoreface sands and lower shoreface facies was circumvented by combined usage of gamma ray, resistivity, neutron and density logs.

The MFS is usually characterized by high gamma, low resistivity (or high resistivity in the case of highly fossiliferous and calcareous hemipelagic shale) and wide separation of neutron and density log pattern compared to their surroundings. Log patterns and sedimentary characteristics were used to identify progradation, retrogradation, aggradation and sequence boundary.

Therefore, the sequences one, two and three identified, their relative genetic facies in association with respective paleobathymetry was achievable through the use of combined complete log suites and sedimentological characteristics. This is an important tool useful for predicting genetically related sediment packages and paleoenvironment of such facies in order to predict and understand the architectural configuration and optimize hydrocarbon exploration of the basin.

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