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Sequence Stratigraphic Analysis of HB-001and HD-001 Wells, Niger Delta Basin, Nigeria

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Abstract

The study investigated the sequence stratigraphy of two wells located within shallow offshore of the Western Niger Delta Basin in Nigeria. The data utilized in the study were obtained from two wells named HB-001 and HD-001. The systems tracts recognized are Lowstand Systems Tracts (LST), Transgressive Systems Tracts (TST), and Highstand Systems Tracts (HST) with stratigraphic surfaces such as Sequence Boundary (SB) and Maximum Flooding Surface (MFS). Four MFS (9.5 Ma), (7.4 Ma), (6.0 Ma), and (5.0 Ma) were identified within the studied intervals by matching with Niger Delta chronostratigraphic chart and global eustatic curve. The Lowstand Systems Tracts (LST) and the Highest Systems Tracts (HST) are potential hydrocarbon reservoirs. A good correlation existed in the wells due to similarities in the lithologies and stratigraphic surfaces. The Highstand Systems Tracts (HST) are potential hydrocarbon reservoirs.

Keywords: *Niger Delta; System tracts; Correlation; Lithologies.*

1. Introduction

The onshore Niger Delta Basin has become mature, and its exploration has shifted offshore. The integration of various geological methods, such as palynological, paleoenvironmental, and sequence stratigraphic analyses, is needed for the understanding of the subsurface geology and the development of its hydrocarbon potentials. The occurrence of hydrocarbon in the Niger Delta Basin has increased the interest of many researchers in the sedimentologic and biostratigraphic characteristics of the basin. The discovery of commercial deposits of hydrocarbon in 1956 began the establishment of the Niger Delta as a world-class petroleum province [1]. Based on available data, sequence stratigraphic interpretation can yield a great geological model. Well-log interpretation may generate detailed results on lithologies and depositional systems. Fossil data may be used to delineate sequence boundaries, chronostratigraphic surfaces, condensed sections, and climatic conditions. Therefore, each discipline, coupled with integrative efforts, is needed to produce this model. The most vital surface in sequence stratigraphy is the sequence boundary. When the sea level falls below coastal sediments, sediments from the fluvial origin will spread out to the basin, where deposition takes place due to the availability of more accommodation space. This allows weathering and erosion of nearshore coastal sediments resulting in an unconformity called the sequence boundary [2]. As a result of relative sea level fall, the occurrence of marine sporomorphs and amorphous organic matter decreases. The amount of land derived sporomorphs and phytoclasts increase [3].

As there is an increase in sea level after a low stand, the rate of increase continues to a point where the rate of increase in accommodation space is more than the sediment influx. This relative increase in sea level produces the first major marine flooding surface known as a transgressive surface. This surface is characterized by the change in deposition from progradational or aggradational parasequence to a retrogradational or landward parasequence [2,4].

The maximum flooding surface tops the transgressive surface and indicates the most landward position of the shoreline. It is the surface where marine encroachment has gone the greatest distance beyond the shelf Retrogradational stacking pattern changes to aggradational or progradational. High levels of bioturbation, glauconite, phosphate, organic matter, and deep marine fossils are signatures of the maximum flooding surfaces due to slow sedimentation rates. Amorphous organic matter are increased, and the number of phytoclasts are reduced [3].

Lying on top of the sequence boundary is the lowstand systems tract, and it marks the end of the sea level fall and the time before sea level rise, leading to the most basinward shift in facies. The characteristic stacking patterns are aggradational or slightly retrogradation. The lowstand systems tracts is bound at the base by the sequence boundary, which is the maximum level of exposure and erosion of underlying strata. Older fossiliferous sediments can be exposed to erosion by relative sea level fall, leading to the occurrence of reworked biofacies once there is a relative increase in sea level. Abundant terrestrial pollen can be found in marine lowstand deposits due to the fluvial transport of organic material to the oceanic basin [4].

A rise in relative sea level leads to the deposition of the transgressive systems tract and a landward shift in facies. The top of the transgressive systems tract is marked by the maximum flooding surface, and the base is marked by the transgressive surface. The rate of increase in accommodation space surpasses the sediment supply during this period leading to retrogradational stacking patterns of sediments. The base of the maximum flooding surface is the highstand systems tracts, while the sequence boundary bounds these systems tracts at the top. There is a decreasing accommodation for sediments, indicating a period of a slowing rate of relative sea level rise. The amount of sediment being supplied exceeds the volume of accommodation space, leading to a progradation of the shoreline basinwards and a change upward from an aggradational to a progradational stacking pattern [2,4-5].

2. Location of the study area and geology of the Niger Delta Basin

HB-001 and HD-001 wells lie within latitudes 4º 08' 48.6" N and 4º 05' 59.6" N and longitudes 5º 58' 40.5" E and 6º 24' 28.6" E, respectively, within the shallow offshore area, western Niger Delta Basin, Nigeria. The names of the wells have been coded by Shell Production and Development Company due to proprietary reasons. The location of the wells is shown in Figure 1 [6-8], which studied the palynocycles, palaeoecology, and system tracts of the Miocene Okan-01 well in the Niger Delta Basin.

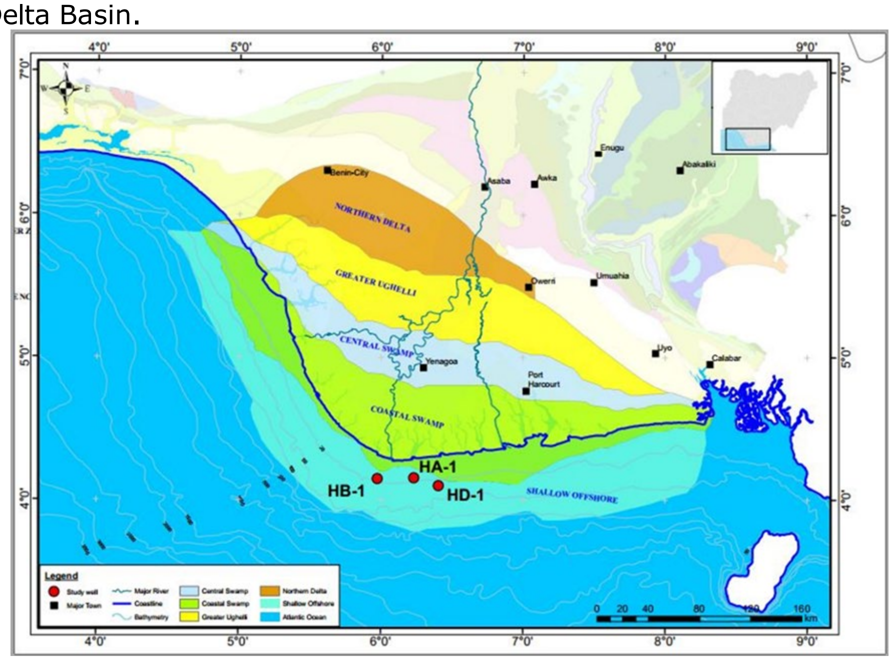

Figure 1. Location Map of the study area within the shallow offshore depobelt of the Niger Delta Basin (modified from [5-6])

The age was identified as Miocene based on the first and last appearance datum of Verutricolporites rotundiporis (BZ6), Racemonocolpites hians (BZ4), Operculodinium centrocarpum (BZ2), and Magnastriatites howardi (BZ1). Nine climatic cycles were recognised and used to infer the depositional cycles that indicate recurrent palynological sequences and vegetation changes based on the sea level changes. The wet cycles suggest highstand transgressive systems tracts, while the dry cycles indicate lowstand systems tracts.

Atta-Petters *et al.* [9] carried out palynofacies and source rock potential analyses on samples from ST-7H well offshore of Tano Basin. Five palynofacies associations were identified using relative abundances of palynomacerals. The oxygenation conditions of the depositional environments were determined subsequently. Aptian to Maastrichtian age has been confirmed using index palynomorphs.

Lucas *et al.* [10] studied the palynofacies of sedimentary intervals of the Ogbabu-1 well in the Anambra basin using sedimentologic and palynological criteria. The shallow marine environment of deposition was delineated for the studied intervals, while the major lithologies encountered were sand and shale. The spore colour index of 4.5 confirms the source rock is immature for the generation of hydrocarbon within the studied interval.

Frederick *et al.* [11] applied sequence stratigraphy and depositional settings in hydrocarbon prospectivity of the Campanian interval in the Tano Basin. Sequence stratigraphic application indicated that the depositional setting of the Campanian interval is characterised by a lowstand fan system deposited in the middle to lower bathyal, deduced from biostratigraphic data. The result revealed that the hydrocarbon prospectivity of the Campanian interval is good, with high chances of stratigraphic traps for reservoirs being sands deposited as channel systems, frontal splays, and lobes.

Five major depobelts (Figure 2) [12] are documented in the Niger Delta Basin Depobelt, with each having its own sedimentation, deformation, and petroleum production history. The oldest is the northern delta province, superimposed comparatively shallow cellar. This depobelt has the growth faults that are described as the oldest, in general, revolving with the increase in seaward steepness. The second is the Greater Ughelli Depobelt.

The third, the central delta province swamp depobelt has well-articulated structures such as a deeper rollover crest that shift seaward for any growth faults. It has two parts: Central Swamp Depobelts I and II, which are well known by some authors as distinct and separate depobelts. The fourth depobelt, which is the Coastal Swamp Depobelt, is located in the far-away delta province. This is the most structurally multifaceted onshore depobelt owing to internal gravity tectonics on the modern continental slope. It also has two parts: Coastal Swamp Depobelts I and II, also considered by some workers as separate entities. The fifth depobelt is the Offshore Depobelt. Again, this can be separated into Shallow Offshore and Deep Offshore Depobelts.

The delta sequence is deformed by synsedimentary faulting and folding. The processes and mechanisms involved in this deformation are still under active discussion. To understand the generation of the tectonic structures, the clay substratum (Akata Formation) must first be looked at closely. The great mass of marine clays of the Akata Formation, which underlie the fluviomarine and fluviatile deposits (of Agbada and Akata Formations), are under-compacted and over-pressured. The clays contain free water, and their bulk density is lower than the density of the overlying sands and compacted shales of the Benin and Agbada Formations. Differential loading of this "clay substratum" has formed gravitational instability to which the mobile clays reacted by the lateral and upward flowage. This mechanism takes place beneath the surface of the Niger Delta Basin.

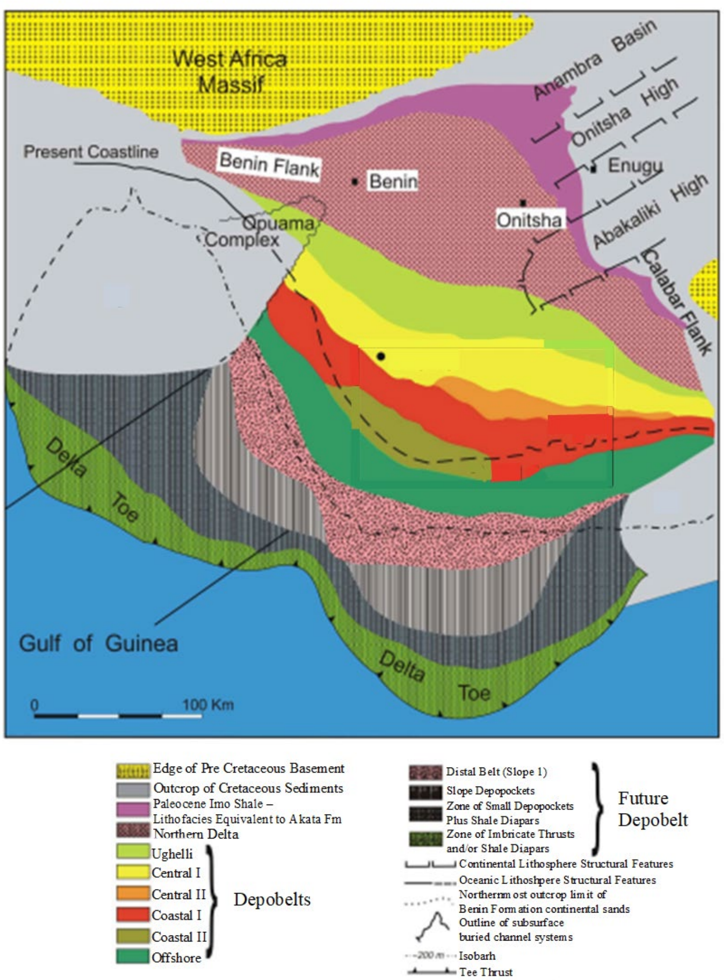

Figure 2. Regional Structural Elements and Depobelts of the Niger Delta Basin (modified after [11])

3. Materials and methods

Sequence stratigraphic involves the description, interpretation, classification, and nomenclature of rock strata on the basis of their stratal stacking patterns and their stratigraphic relationships. All units and surfaces of stratigraphic sequence can be studied at different scales depending on the objective of the study and the type of available data, which can include palynomorph, palynomaceral, well log signatures, and ditch cutting samples. The model-independent approach of [13] cut across the different sequence stratigraphic methods and depends on a set of core principles. The approach is simpler than the methodology of any model, therefore promoting better flexibility in its application. The model-independent methodology of [13] (Figure 3) was used for this study. It involves the examination of the local data from the studied wells and the observation of the features that will aid the identification of stratal stacking patterns based on the available data.

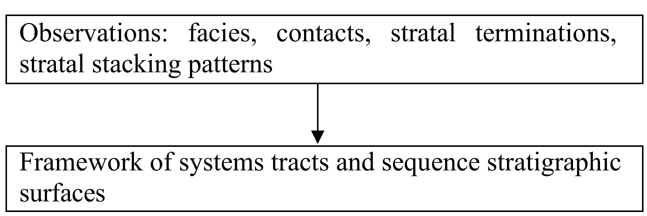

Figure 3. Model-independent method of sequence stratigraphic analysis [13]

4. Result and discussion

4.1. Sequence stratigraphy of HB-001 and HD-001

The sequence stratigraphic results of the two wells are presented in Figures 4 and 5. In this study, four Maximum Flooding Surfaces and three Sequence Boundaries were identified within the studied intervals in the two wells. System tracts were also identified within the depositional sequences bounded by the Maximum Flooding Surfaces of [13].

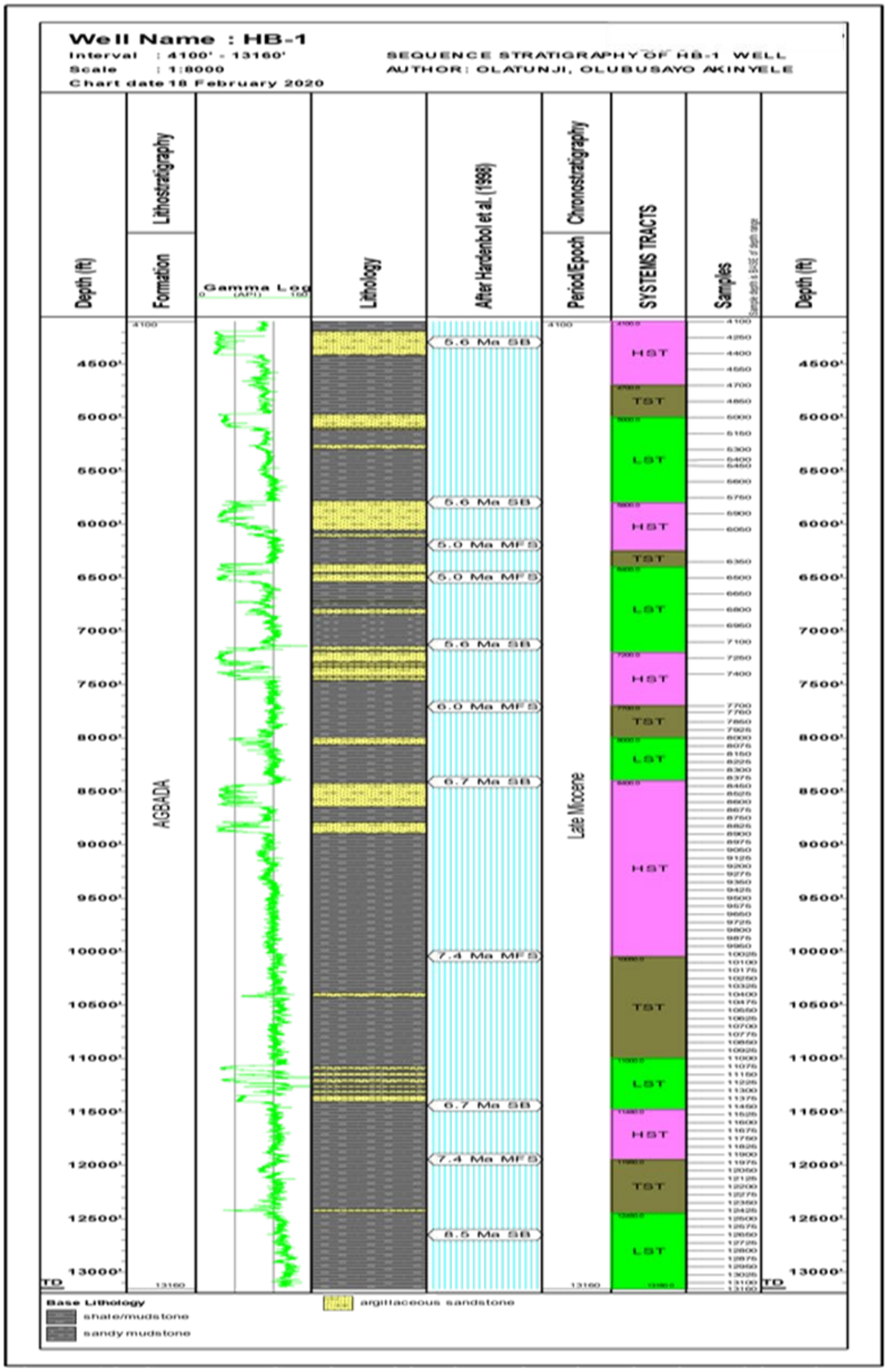

Figure 4. Sequence stratigraphic chart of HB-001 well

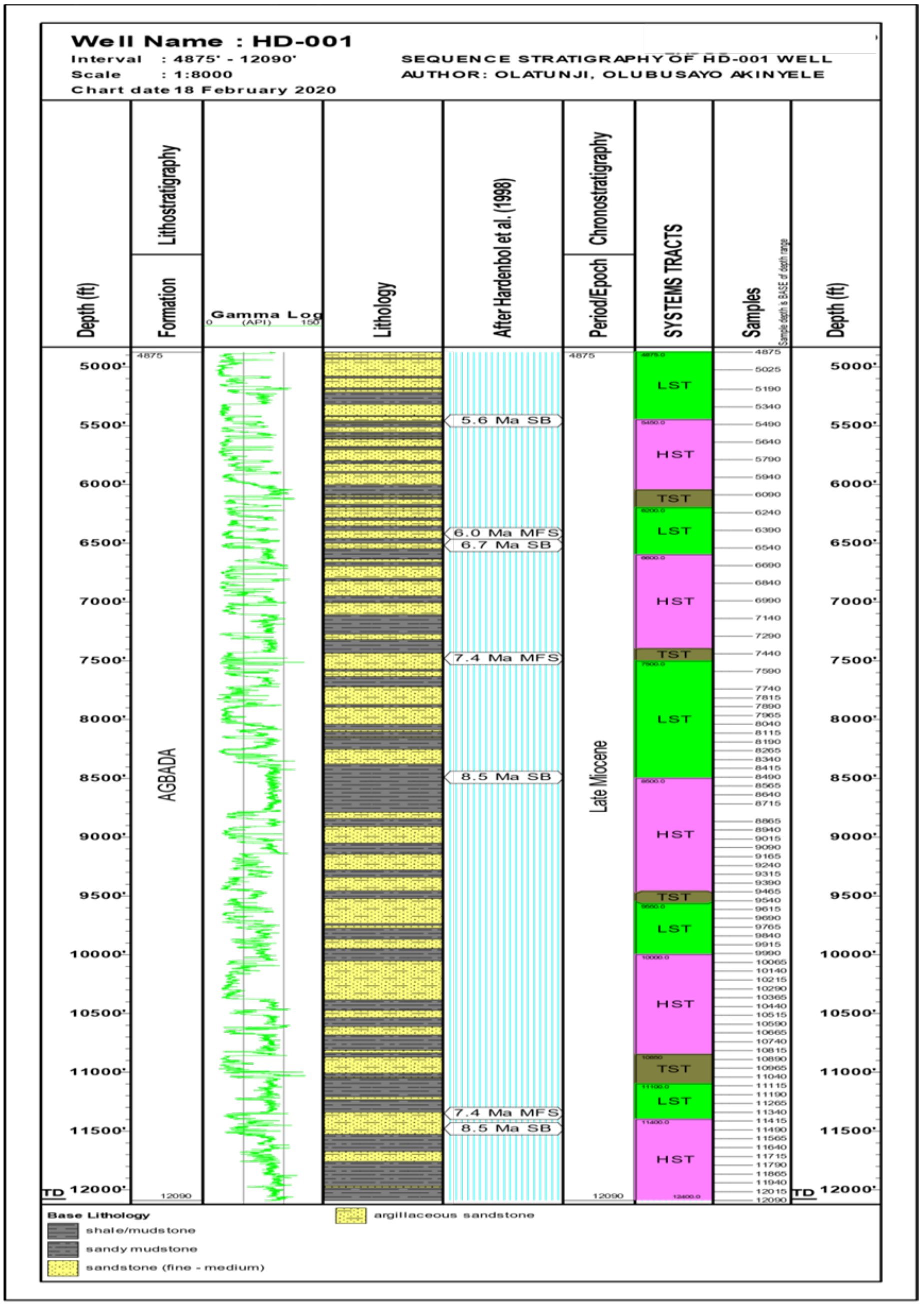

Figure 5. Sequence stratigraphic chart of HD-001 well

Palyno-ecological groupings of palynomorphs of [8] show that an increase in the mangrove, freshwater, and rainforest taxa with a decrease in savannah and Montane taxa indicate well climate and Highstand System Tract (HST) while the increase in savannah and montane taxa with a decrease in a mangrove, freshwater, and rainforest taxa indicate dry climate and Lowstand System Tracts (LST) (Figures 6 and 7). Potential hydrocarbon reservoirs and cap rocks can be found within the sandstone and shale units of the depositional sequences. The Maximum Flooding Surfaces are the shaliest points, as implied by Gamma Ray Log for the studied wells. There is high delivery and abundance of pollen and spores with an abundance of small and medium-sized palynomaceral 1 and 2 in the Maximum Flooding Surface (MFS). There is a low recovery of pollen, spores, and palynomacerals at the Sequence Boundaries. The surfaces are dated based on their stratigraphic positions in the sequence.

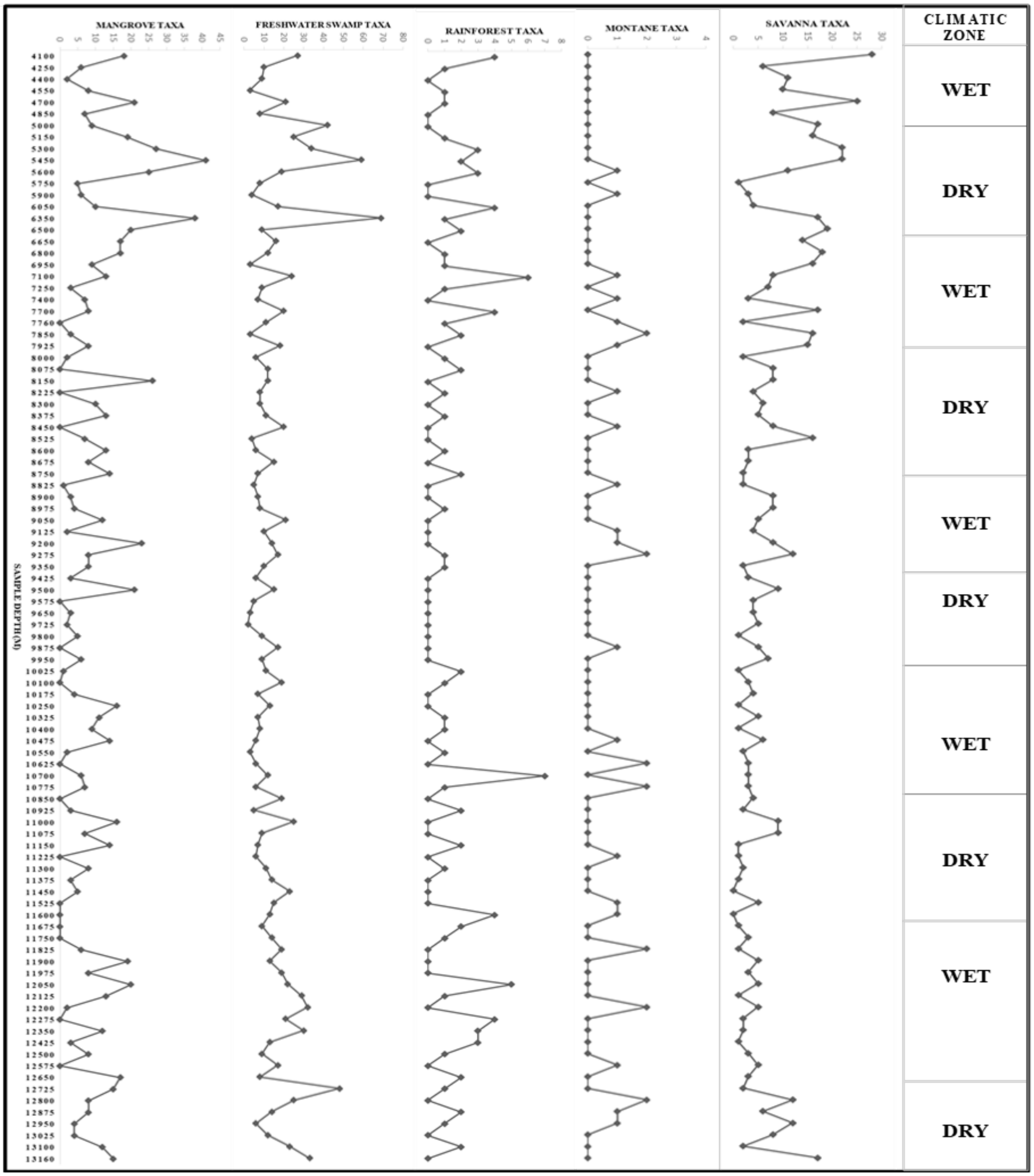

Figure 6. The Abundance (Population Count) of the Palyno-ecological Groups and Paleoclimate Zones of HB-001 Well

4.2. Stratigraphic Surfaces in HB-001 Well

Six candidate Sequence Boundaries and four Maximum Flooding Surfaces were identified. The Sequence Boundaries SB1 (8.5 Ma), SB2, SB3 (6.7 Ma), SB4 (5.6 Ma), and SB5 were delineated at approximate depths of 12650, 11440, 8410,7125, 5793, and 4295 ft, respectively while the maximum flooding surfaces MSF1, MFS2 (7.4 MA), MFS3 (6.0 MA) and MFS4 (5.0 MA) were delineated at approximate depths of about 11945, 10040, 7708, 6192 and 6495 ft respectively. The associated palynomacerals consist of diverse and abundant pollen, spore, abundant medium-sized PM 1 and 2, and few occurrences of large sized PM 1 and 2. The surfaces are correlated to the Niger Delta Cenozoic Chronostratigraphic Chart (Figure 8).

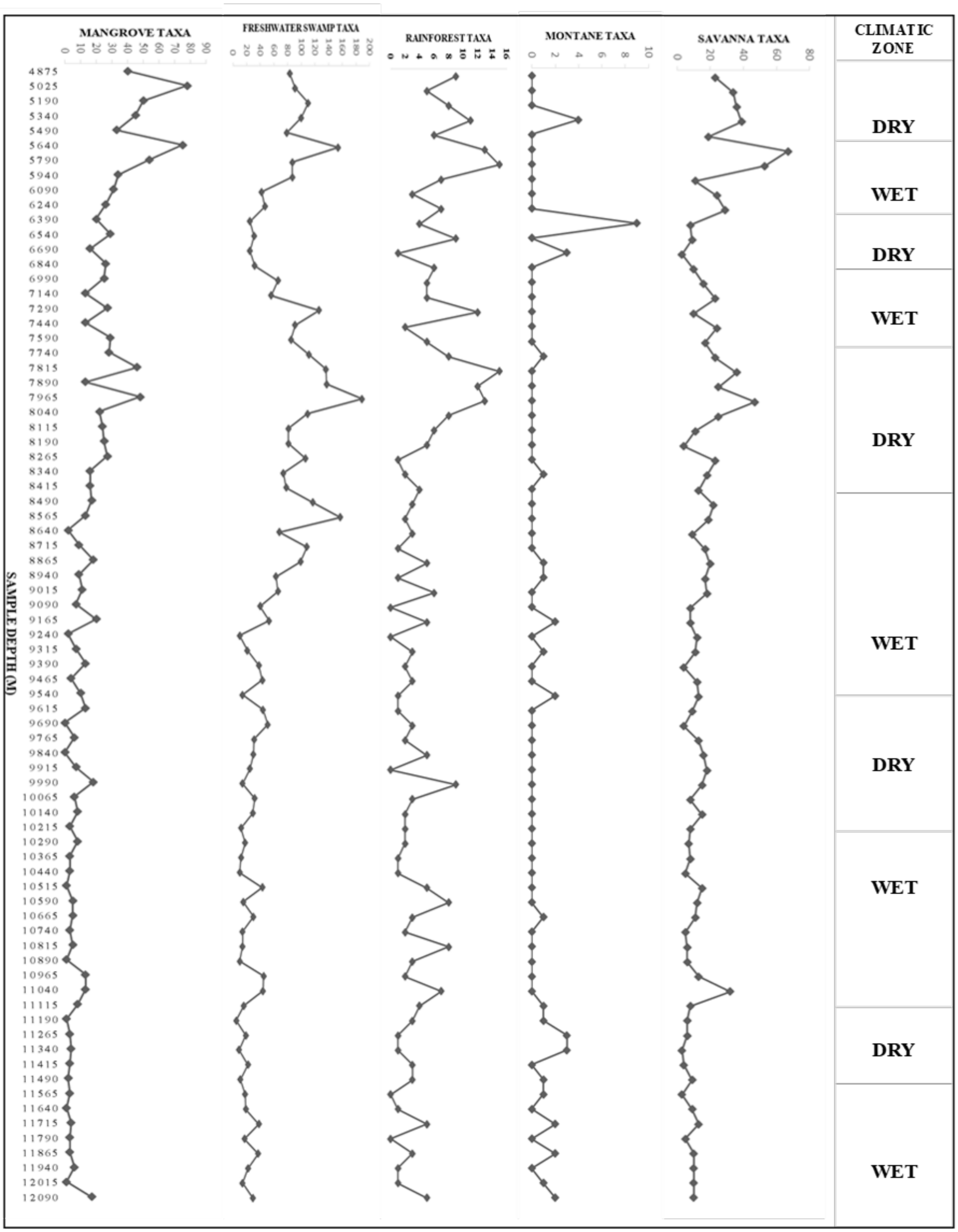

Figure 7. The Abundance (Population Count) of the Palyno-ecological Groups and Paleoclimate Zones of HD-001 Well

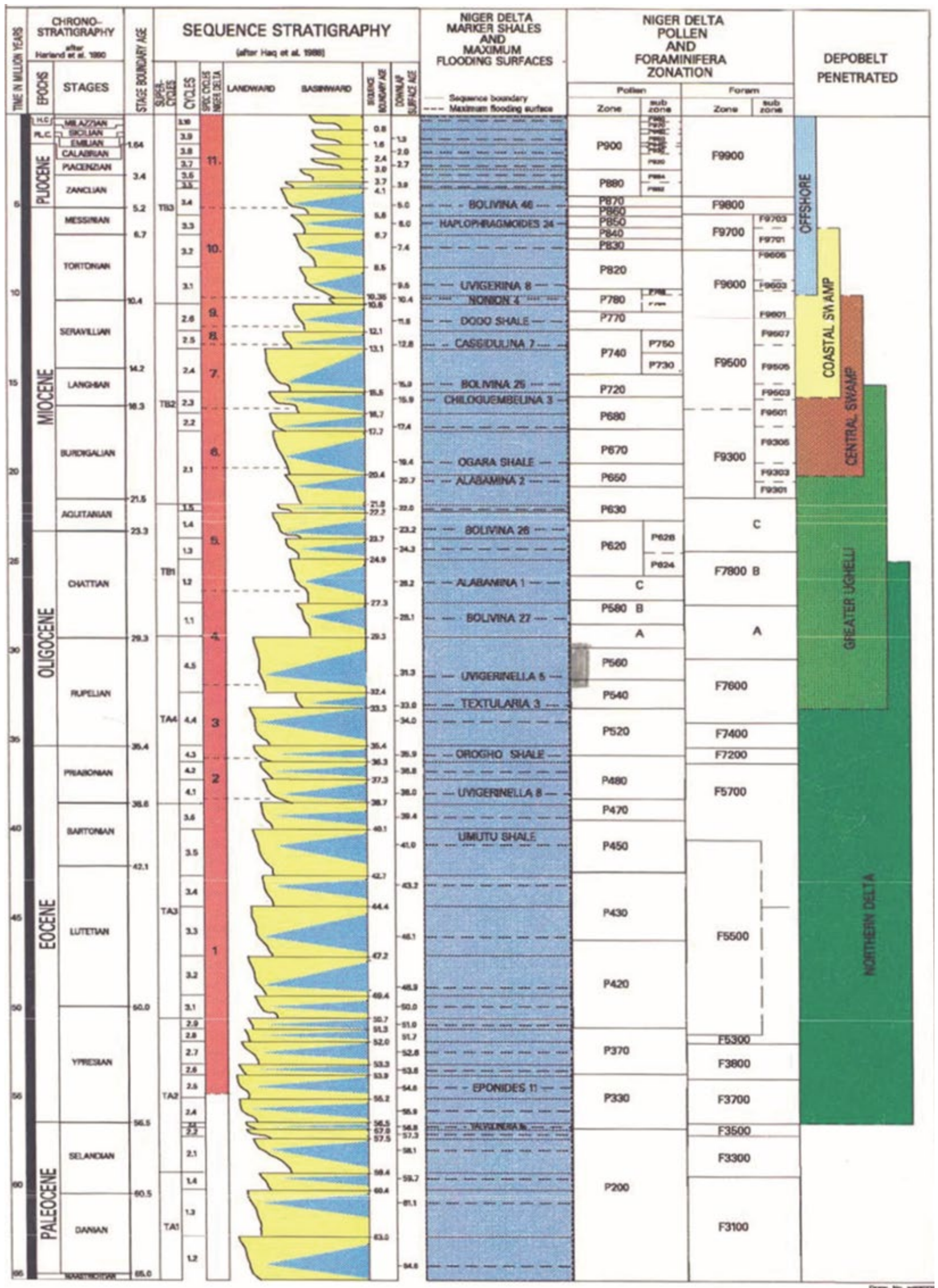

Figure 8. Correlation of the stratigraphic surfaces in HB-001 and HD-001 Wells with the Niger Delta Cenozoic chronostratigraphic chart

4.3. Depositional sequences in HB-001 well

Based on the identified stratigraphic surfaces, 5 depositional sequences were identified. These are Sequence1 (bounded by SB1 and SB2), Sequence2 (bounded by SB2 and SB3), Sequence3 (bounded by SB3 and SB4), Sequence 4 (bounded by SB4 and SB5) and Sequence6 (bounded by SB5 and SB6).

(i) Sequence 1: The lowstand system tract unit of this sequence is relatively thin with an upward coarsening stacking pattern that is characteristic of a lowstand prograding wedge; bounded above by the transgressive surface occurring at approximately 12395 ft. overlying the transgressive sand is the fining upward shaly transgressive system tract unit which is capped beneath the MFS1. The highstand system tract unit overlying the MFS1 is characterised by a shale build-up that is suggestive of a period of relative sea level standstill that ended in the rapid fall that resulted in the SB2.

(ii) Sequence 2: Overlying the SB2 is the lowstand system tract unit, also characterised as a lowstand prograding wedge due to its log signature and stacking pattern. It is bounded above by the transgressive surface at approximately 11040 ft. The transgressive system tract overlying (bounded above by MFS2) the transgressive sand is predominantly shaly with an observable streak of sand. The highstand system tract unit overlying the MFS2 and capped above by the SB3 is composed of an aggrading shale that grades upwards in prograding sands.

(iii) Sequence 3: Overlying SB3 is the LST unit that is characterised by overall upward coarsening indicative of a lowstand prograding wedge. At the onset of transgression (TS), the transgressive system tract unit was deposited, culminating in the overlying MFS3. Overlying the MFS3 is the highstand system tract unit comprising an aggrading shale overlain by prograding sands. Sequence4 and 5 are the same as sequence 3; differences are only in the surfaces and their depths.

4.4. Stratigraphic Surfaces in HD-001 Well

Based on the wireline logs, the abundance, and diversity of palynomorphs and palynofacies provided for the study. Five (5) Sequence Boundaries and 4 Maximum Flooding Surfaces were identified in the well. The recognition of these surfaces was done using similar techniques as in the HB-001 well. The Sequence Boundaries SB1 (8.5 Ma), SB2, SB3 (6.7 Ma), SB4 (5.6 Ma), and SB5 were found to occur at approximate depths of about 11350, 10040, 8470, 6550, and 5220 ft, respectively while the Maximum Flooding Surfaces MFS1, MFS2 (7.4 Ma), MFS3 (6.0 Ma) and MFS4 were delineated at 10710, 9450, 7350 and 6040 ft respectively. These MFS depths are associated with major pollen, spores, PM 1 and 2 abundance, and diversity peaks. The vertical sections penetrated by the well were subdivided into sequences and their associated systems tracts on the basis of these surfaces. The surfaces are correlated to the Niger Delta Cenozoic Chronostratigraphic Chart (Fig. 8).

4.5. Depositional sequences in HD-001 well

Four sequences were delineated within the HD-001 well. These are Sequence 1 (bounded below by SB1 and above by SB2), Sequence 2 (bounded below by SB2 and above by SB3), Sequence 3 (bounded below by SB3 and above by SB4), and Sequence 4 (bounded below by SB4 and above by SB5).

(i) Sequence 1: Directly overlying the SB1 is the lowstand system tract unit characterised by a basal internal retrogradation but an overall progradation, which is diagnostic of the lowstand prograding wedge. The palynofacies association consists of a low abundance of mangrove, freshwater, and rainforest taxa and an increased occurrence of montane and savanna taxa. Large-sized PM 1 and 2 are also common. The upper part of the lowstand systems tract shows a blocky to crescentic log motif that is suggestive of fluvial channel deposits that forms to the maximum limit of relative sea-level fall of a transgressive surface at 10820 ft). Overlying the TS is a thin transgressive system tract unit shale that is bounded above by the MFS1.

(ii) Above the MFS1 are the relatively blocky sandy units of the highstand system tract which are characterised by thin internal shale build-ups. The unit is bounded by the SB2,

(iii) Sequence 2: The LST unit is a lowstand prograding which is characterised by a coarsening-up unit indicating a transition from a shale-rich to the shale-free system. The lowstand system tract is bounded above by a transgressive surface (at a depth of about 90540 ft). Above the TS and the overlying MFS2 is a thin transgressive system tract shale that shows a fining upward motif. Overlying the MFS2 is the highstand systems tract unit which is characterised by alternating fining up and coarsening up units that indicate fluctuation in relative sea level positions. The unit is bounded above by the SB3.

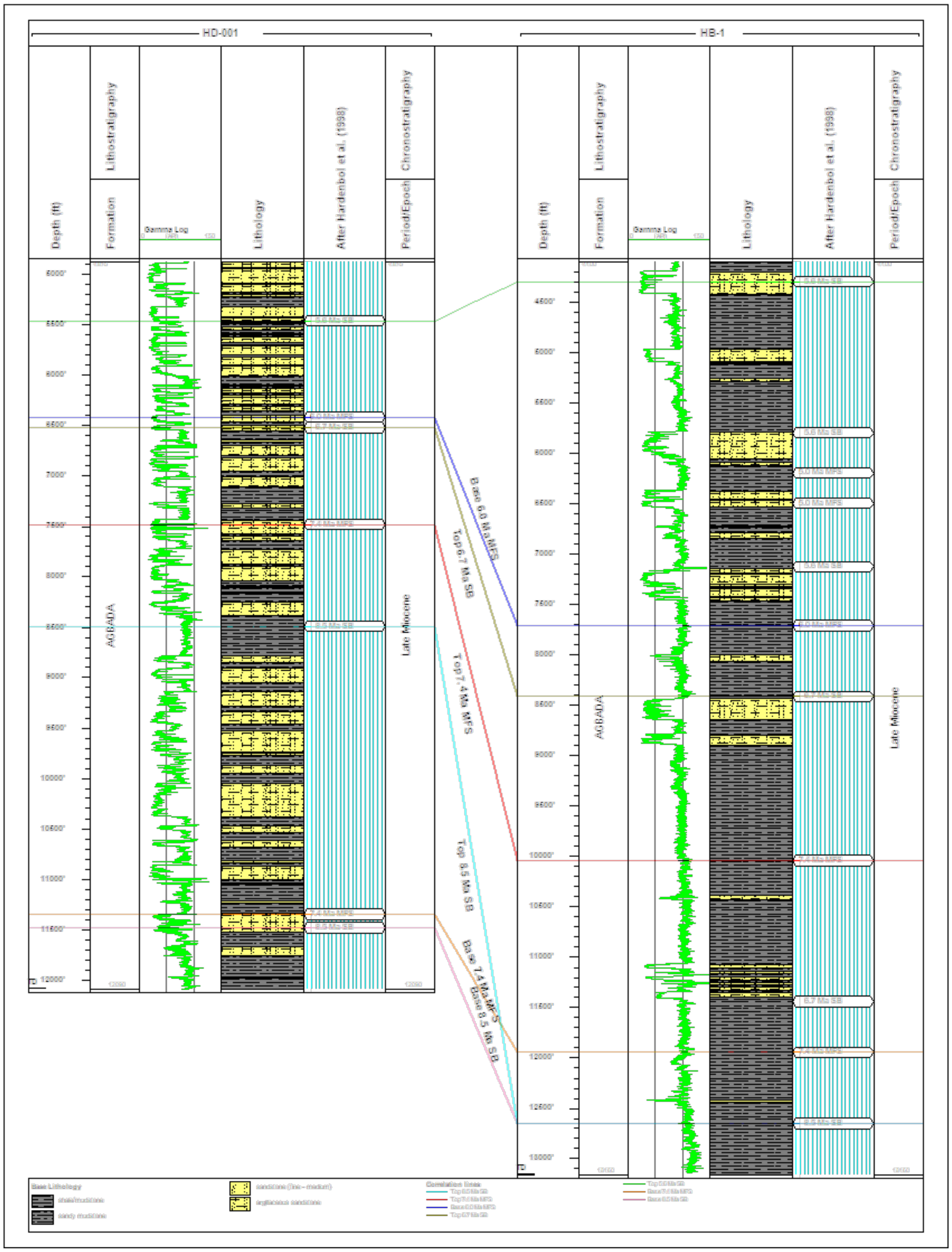

Figure 9. Correlation chart for Sequence stratigraphy of HB-001 and HD-001 Wells

(iv) Sequence 3: The lowstand systems tract unit of this sequence is characterised by an overall coarsening-up unit with intermittent shale intercalations, bounded above by a transgressive surface at a depth of about 7410 ft. Overlying the TS is a thin transgressive system of tracts shale bounded at the top by the MFS3. The highstand system tracts are predominantly sandy with intermittent shale presence.

(v) Sequence 4: Bounded below by the SB4 and above by a TS (at a depth of about 6100 ft), the LST unit is blocky sand characteristic of fluvial channel deposits, with shale intercalations at intervals. The TST is relatively thin and bounded above the MFS4. Above the MFS4 are the highstand system tracts deposits that show initial progradation and later aggradation.

4.6. Correlation of sequence stratigraphy of HB-001 and HD-001 wells

The correlation of the relationships between well tops and stratigraphic surfaces was carried out to further enhance the surface architecture of the studied wells. The integration of lithologic attributes and wireline logs allowed the correlation of the sequences in the studied wells. The sequence stratigraphic correlation chart (Figure 9) shows that the sequences and surface identified in the wells showed the presence of lateral continuity in lithologies and horizons in the studied area. This is significant in the exploration of hydrocarbon.

5. Conclusion

Sequence stratigraphy analyses were carried out within the sedimentary section penetrated in HB-001 and HD-001 wells, using ditch-cutting samples and wireline logs provided by Shell Production and Development Company. Ninety-six and Seventy-seven ditch-cutting samples within the depth intervals of 4100 – 13160 ft and 4875 – 12090 ft in HB-001 and HD-001 wells, respectively, were analysed. Lowstand Systems Tracts, Transgressive Systems Tracts, and Highstand Systems Tracts were recognized on the basis of Gamma Ray Logs signatures, lithology, abundance, and diversity of palynomorphs and palynofacies. Chronostratigraphic surfaces such as Sequence Boundary, Maximum Flooding Surfaces, and Transgressive Surfaces were also identified. The Sequence Boundaries and Maximum Flooding Surfaces were dated 8.5 Ma, 6.7 Ma, 5.6 Ma and 7.4 Ma, 6.0 Ma, 5.0 Ma, respectively, by correlation to the Niger Delta Cenozoic chronostratigraphic chart and the global sequence chart of [14].

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