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Sequence Stratigraphic Evaluation of Sediments Domicile in Day Field Located in the Onshore Central Swamp Depobelt of the Niger Delta, Nigeria

***[1]ALEGE, TS**

Department of Geology, Federal University, Lokoja, Nigeria
*`*Corresponding author: topeemma12@gmail.com*

ABSTRACT: This study employs the tool of sequence stratigraphy to evaluate Day Field, in the Onshore Niger Delta of Nigeria for hydrocarbon predictions using six (6) well logs displayed at standard scales to enhance log trends for lithologic and stratal package delineation. The identified key stratigraphic bounding surfaces were tied to well-defined palynological (P) zone and foraminiferal (F) zones with the aid of the biostratigraphic data and calibrated using the Niger Delta Chronostratigraphic chart. Five (5) MFSs (34.0, 33.0, 31.3, 28.1, and 26.2 Ma) and six (6) SBs (35.4, 33.3, 32.4, 29.3, 27.3, and 24.9 Ma) were delineated. The stratigraphic surfaces were matched with the palynological (P480– P580) and foraminiferal zones (P20/N1–P22/N3) encountered. The results indicate that the study area is of Late Eocene to Late Oligocene age (26.2–35.9 Ma). The key stratigraphic surfaces also reflect a series of relative sea-level falls (regressive episodes) and sea-level rises (transgressive episodes) that are regionally extensive and correlated across the wells. Five sequences (SEQ1–SEQ5) were recognized, SEQ1 and SEQ5 comprising three system tracts (LST, TST, and HST) revealing four third-order depositional sequences (classified as type 1 sequence), while SEQ2-SEQ4 comprises two system tracts (TST and HST). Two depositional environments were interpreted from the log trends; the Fluvial (shoreface) and Tidal environments. The hydrocarbon exploration prospects identified are the sand units of the LST and HST combining with the shale units of the TST offering good reservoir and seal/source rocks respectively.

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Keywords: sequence stratigraphy, Niger Delta, stratigraphic surfaces, chronostratigraphy

Sequence Stratigraphy is an important tool for correlation and mapping of sedimentary facies, and stratigraphic prediction (Catuneanu, 2006). It has contributed immensely in revolutionizing the stratigraphic analysis of the hydrocarbon industry especially in the Niger Delta. The Niger Delta is ranked among the world's major hydrocarbon provinces (Kulke, 1995) which has necessitated a continuous search and re-evaluation of the oil fields in the region with sequence stratigraphic analysis playing a major role as it can be integrated with well logs, seismic data, biostratigraphic data, and core data. Many researchers have engaged the tool of sequence stratigraphy in unravelling some of the complexities of hydrocarbon exploration in the Niger Delta. Nton and Ogungbemi (2011) integrated well logs and biostratigraphic data to identify three depositional sequences and a marker shale characterized by Chloguebelina 3 (16.0 Ma) to date the key bounding surfaces of K-Field in the Niger Delta. Sequence stratigraphic tool was also employed to interprete the lithofacies and depositional environment of Akos Field in the Coastal Swamp Depobelt of The Niger Delta. Four major sequence boundaries and three intervening Maximum Flooding Surfaces (MFS) were recognized to have been deposited within the shallow Inner-Neritic to the Middle-Neritic environments (Alege, 2017; Alege et al., 2020). Furthermore, Oyetade et al. (2020) also identified key stratigraphic surfaces and depositional sequences to delineate and correlate potential hydrocarbon reservoirs in OSP field of the Niger Delta. This study seeks to improve on existing knowledge of sequence stratigraphy by delineating, correlating sequences and key stratigraphic surfaces to determine the environment of deposition of the sediments domicile in Day Field

*`*Corresponding author: topeemma12@gmail.com*

located in the onshore Central Swamp depobelt of the Niger Delta, Nigeria (Figure 1).

MATERIALS AND METHODS

Brief Description of the Study Area: Three lithostratigraphic units have been recognized in the subsurface of the Niger Delta. These ranges from the oldest to the youngest; the Akata, Agbada, and Benin Formations all of which are strongly diachronous (Short and Stauble, 1967). It is a prograding complex that is characterised by a coarsening upward regressive sequences (Figure 2).

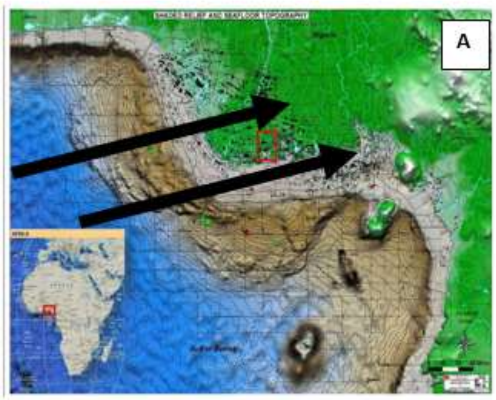

Fig 1 A. Inset map of the Niger Delta Basin in Africa and location map of the study area (red rectangle) showing relief and oil and gas concessions (source: Ejedawe, et al. 2007)

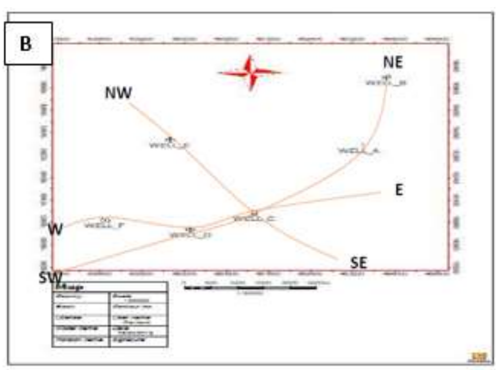

Fig 1B. Map showing well distribution in Day field

The Niger Delta as a prograding sedimentary complex is characterized by a coarsening upward regressive sequences. The overall regressive sequence of clastic sediments was deposited in a series of offlap cycles that were

Data Collection: Six (6) well logs from the Central Swamp Depobelt of the Niger Delta were made available for this study. The area falls within the concession of Agip Petroleum. The original names of the wells are concealed due to proprietary reasons. The objective seeks to do the following: Delineating, Correlating sequences and Key stratigraphic surfaces to determine the environment of deposition of sediments in the study area. The well log analysis was carried out by delineating the different lithologies on the gamma-ray log into sand and shale using an API scale of 0-150. The log trends (Figure 3) were used in identifying the parasequence stacking patterns.

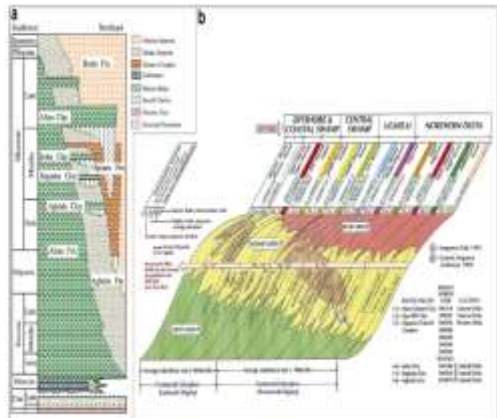

Fig 2. Stratigraphy of Niger Delta Basin; a) Stratigraphic column of the Niger Delta (modified from Doust and Omatsola, 1990). b) Diagrammatic representation of the stratigraphic evolution of the Niger Delta (after Reijers 2011)

The identified key stratigraphic surfaces such as maximum flooding surfaces (MFSs), dated with marker shales and sequence boundaries (SBs) identified, were tied to well-defined Palynological (P) zone and foraminiferal (F) zones. MFSs were represented by thick and extensive shale unit intervals in well logs that separated overall fining or thinning-upward intervals from coarsening- or thickening upward intervals. The systems tracts were delineated based on the transgressive and regressive curves (Van Wagoner et al. 1990) defined by their position within sequences and stacking pattern of successive parasequences.

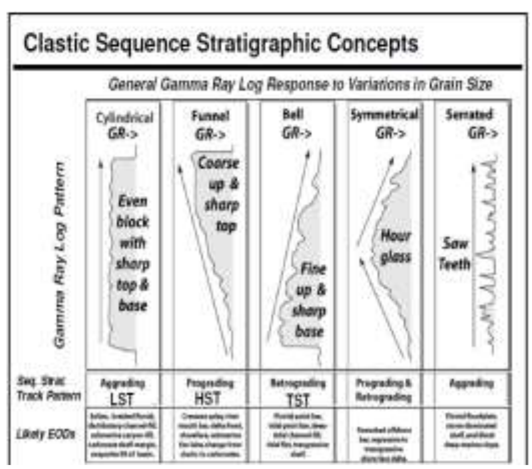

Fig 3. Facies stacking patterns and gamma ray log responses (after Emery and Myers, 1996)

Well correlation across logs was achieved using the identified key stratigraphic surfaces (sequence boundaries (SB) and maximum flooding surfaces (MFS)). The surfaces were constrained with the aid of the biostratigraphic data to correlate the sand units across the wells and calibrated using an established Niger Delta Basin zonation scheme (Figure 4). All these results were combined to interprete the depositional environment of Day Field.

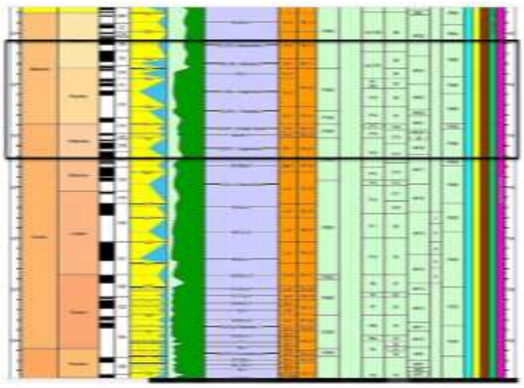

Fig 4: Niger Delta chronostratigraphic chart showing geologic interval (Late Eocene-Late Oligocene) interest in the black box (After Haq.et al. 1988)

RESULTS AND DISCUSSION

Sequence Stratigraphic Correlation: Eleven stratigraphic bounding surfaces (Six SBs and five intervening MFSs) recognized in this study were used for well log sequence stratigraphic correlation.

Maximum Flooding Surfaces (MFS): Five (5) MFSs were identified and tied to their corresponding biozones using the Niger Delta biozonation scheme (figure 4). The oldest MFS within the study area is 34.0 Ma. It was correlated across WELL_A, C, D, E, and F (figures 5, 7, 8 and 9) but was not seen in WELL_B (Figure 6) and was dated 34.0 Ma using Ru-2-Textularia-3 regional marker. The surface occurrence of this event is within P560 and P20/N1 biozones. The 33.0 Ma Maximum Flooding Surface (MFS_33.0), correlated across all wells and belongs to the Ru-1-Textularia-3 Shale regional marker. This surface occurred within P560-P540 and P20/N1 biozones. 31.3 Ma Maximum Flooding Surface (MFS_31.3), correlated through the entire well in the field and was dated 31.3 Ma using the Ru-2-Uvigerinella-5 regional marker. This MFS occurred within P580 and P21/N2 biozones. 28.1 Ma Maximum Flooding Surface (MFS_28.1), it was identified and correlated across all wells. This surface was dated 28.1 Ma using the Ch-1-Bolivina-27 regional marker. The MFS occurred within P580 and P22/N3 biozones. The youngest is the 26.2 Ma Maximum Flooding Surface (MFS_26.2), correlated across all wells. This surface was dated 26.2 Ma using the Ch-2-Alabammina-1 marker. This MFS occurred within P580 and P22/N3 biozones.

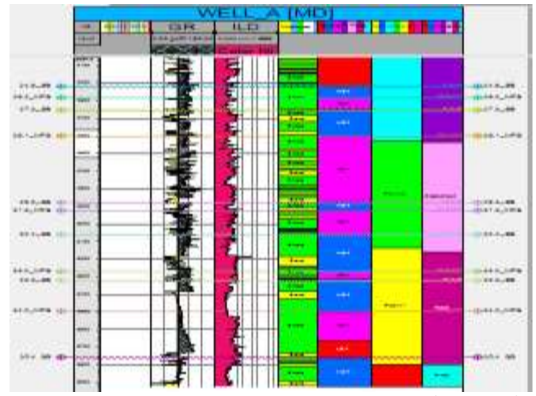

Fig 5. Day-A showing the chronostratigraphic significant surfaces, systems tract and depositional sequences

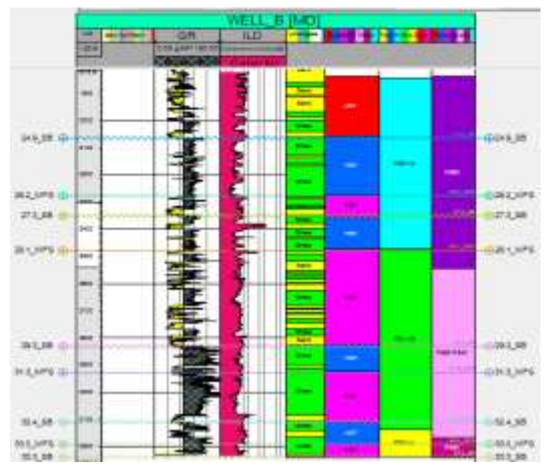

Fig 6. Day-B showing the chronostratigraphic significant surfaces, systems tract and depositional sequences

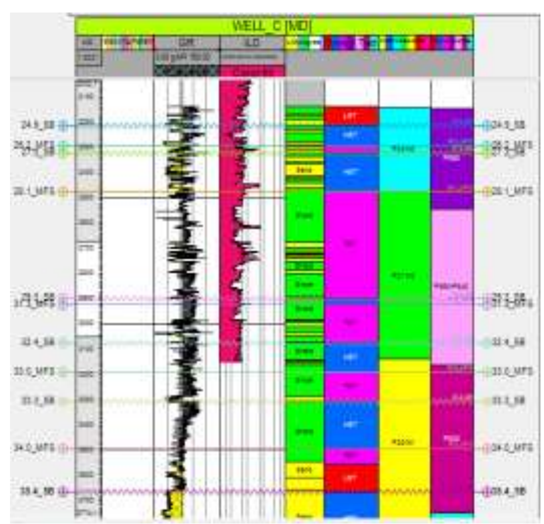

Fig 7. Day-C showing the chronostratigraphic significant surfaces, systems tract and depositional sequences

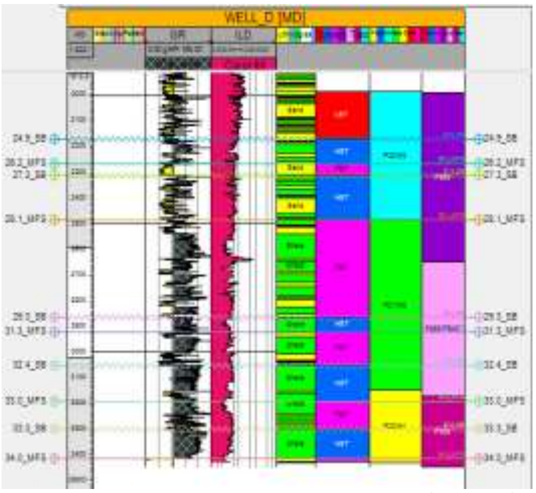

Fig 8. Day-D showing the chronostratigraphic significant surfaces, systems tract and depositional sequences

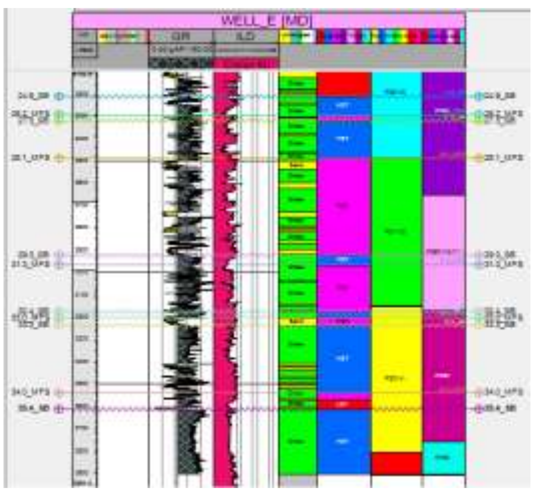

Fig 9. Day-E showing the chronostratigraphic significant surfaces, systems tract and depositional sequences

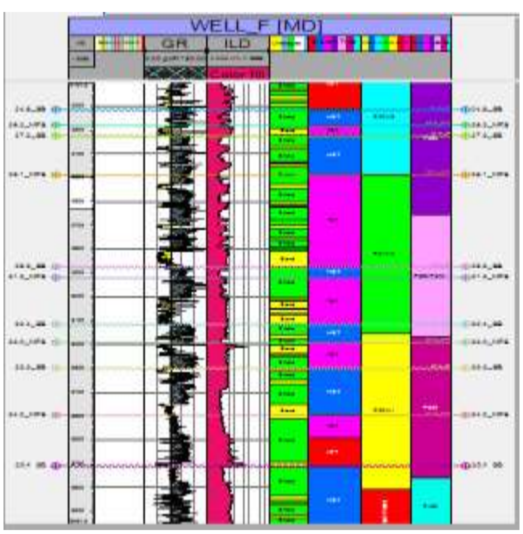

Fig 10. Day-F showing the chronostratigraphic significant surfaces, systems tract and depositional sequences

Table 1. Day Well A-F and the depth of occurrence of stratigraphic surfaces

WELL ID	MD (m)	SURFACE
A	2218.53	24.9 SB
A	2283.24	26.2 MFS
A	2353.97	27.3 SB
A	2500.7	28.1 MFS
A	2879.18	29.3 SB
A	2923.58	31.3 MFS
A	3060.52	32.4 SB
A	3270.46	33.0MFS
A	3321.62	33.3 SB
A	3496.19	34.0 MFS
A	3758.05	35.4 SB
B	2063.28	24.9 SB
B	2275.9	26.2 MFS
B	2349.47	27.3 SB
B	2477.32	28.1 MFS
B	2829.82	29.3 SB
B	2925.78	31.3 MFS
B	3108.18	32.4 SB
B	3189.59	33.0MFS
B	3237.4	33.3 SB
C	2212.14	24.9 SB
C	2292.24	26.2 MFS
C	2321.4	27.3 SB
C	2475.55	28.1 MFS
C	2899.38	29.3 SB
C	2921.25	31.3 MFS
C	3075.29	32.4 SB
C	3190.83	33.0MFS
C	3307.29	33.3 SB
C	3495.42	34.0 MFS
C	3665.89	35.4 SB
D	2169.49	24.9 SB
D	2265.6	26.2 MFS
D	2311.86	27.3 SB
D	2484.76	28.1 MFS
D	2863.37	29.3 SB
D	2920.95	31.3 MFS
D	3051.53	32.4 SB
D	3190.8	33.0MFS
D	3298.74	33.3 SB
D	3414.23	34.0 MFS
E	2212.06	24.9 SB
E	2294.55	26.2 MFS
E	2319.67	27.3 SB
E	2488.24	28.1 MFS
E	2922.79	29.3 SB
E	2966.31	31.3 MFS
E	3176.7	32.4 SB
E	3201.14	33.0MFS
E	3236.52	33.3 SB
E	3539.44	34.0 MFS
E	3612.11	35.4 SB
F	2215.51	24.9 SB
F	2280.66	26.2 MFS
F	2325.39	27.3 SB
F	2488.25	28.1 MFS
F	2874.74	29.3 SB
F	2920.91	31.3 MFS
F	3115.46	32.4 SB
F	3299.73	33.0MFS
F	3191.6	33.3 SB
F	3496.63	34.0 MFS
F	3710.07	35.4 B

Sequence Boundaries: (SB) Six (6) sequence boundaries were identified in the study area (Figures

5-10) and these include SB_24.9 Ma, SB_27.3Ma, SB_29.3 Ma, SB_32.4 Ma, SB_33.3 Ma and SB_35.4 Ma (Table 1). SB_35.4 Ma, which was the oldest sequence boundary identified was not correlated across the wells.

System Tracts: Three system tracts recognised are the Lowstand Systems Tract (LST), Transgressive Systems Tracts (TST) and Highstand Systems Tract (HST) (Figures 11-15). These system tracts are characterized by variable thicknesses that appear to be structurally controlled. The average distribution of these system tracts is such that there is a higher percentage of HST (40%) relative to LST (10%) and much lesser TST (50%) packages. The HST packages characterized by a coarsening upward profile are indicative of the shoreface environment due the concentration of the largest amount of sands within the units. The finning upward pattern of the TST is interpreted to be a tidal environment.

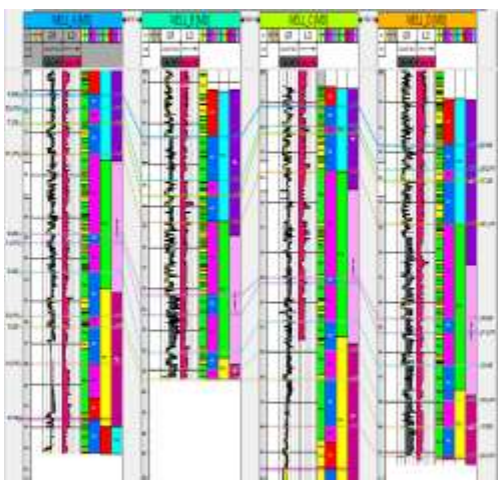

Fig 11. Well log sequence stratigraphic correlation and interpretation across dip (NE-SW) within the wells.

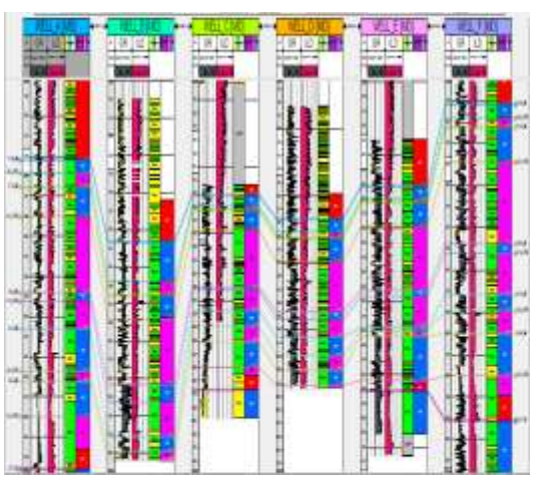

Fig 12. Well log sequence stratigraphic correlation and interpretation

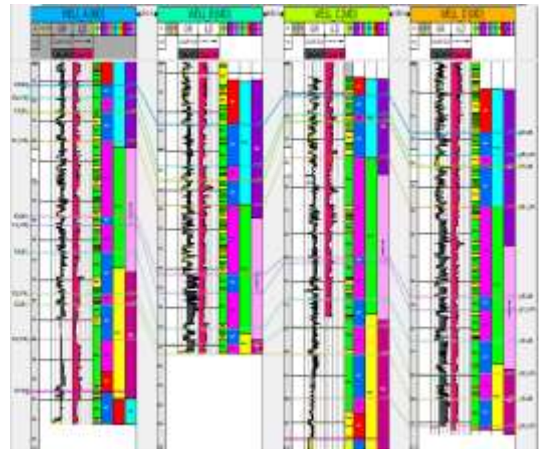

Fig 13. Well log sequence stratigraphic correlation and interpretation across dip (NE-SW) within the wells.

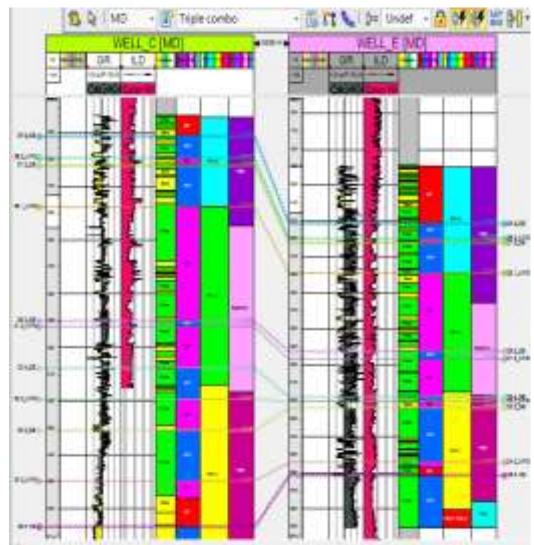

Fig 14. Well log sequence stratigraphic correlation and interpretation across dip (NE-SW) within the wells.

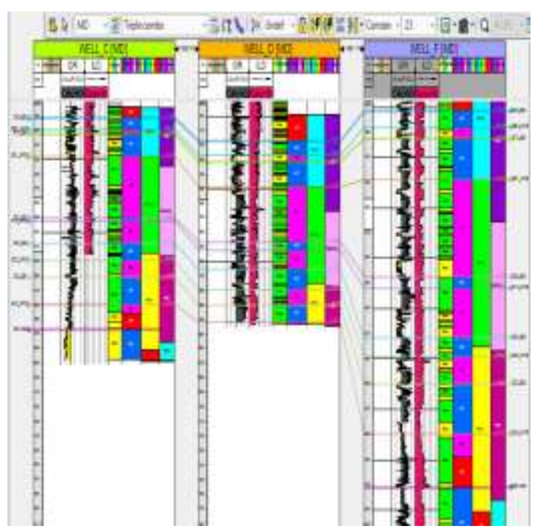

Fig 15. Well log sequence stratigraphic correlation and interpretation across strike (E-W) within wells C, D and F.

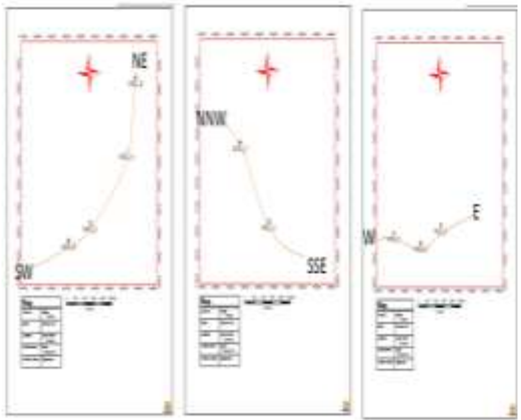

Fig 16: Base map showing dip and strike line across correlated wells

Depositional Sequences: Five depositional sequences depicted as SEQ1, SEQ2, SEQ3, SEQ4, and SEQ5 were recognized. The component system tracts were correlated and interpreted across the fields based on stacking pattern and log motifs in various wells, and the spatial distribution of the recognized constrained stratigraphic surfaces (MFSs and SBs) gave insight into these depositional sequences.

SEQ 1 is approximately 410m thick and is bounded top and bottom by SB_33.3 Ma and SB_35.4 Ma, respectively, the sequence is incomplete. The lowstand system tract sand represents deposits in proximal fluvio-marine (PFM) and shallow neritic settings. The transgressive system tract unit of this sequence is capped by the 34.0-Ma MFS marker (Ru-2-Textularia-3). The highstand system tract is deposited in the inner-middle neritic setting depicting mainly progradational-retrogradational stacking patterns.

SEQ 2 is approximately 185m thick and is bounded top and bottom by 32.4 and 33.3 Ma sequence boundaries respectively. The HST of this sequence is deposited in the shallow to inner neritic depositional settings. The TST of SEQ2 is capped by 33.0-Ma MFS marker (Ru-1-Textularia-3).

SEQ 3 is approximately 240m thick, and it is bounded top and bottom by the 29.3- and the 32.4-Ma SBs, respectively. The sequence displayed predominantly fluvial and tidal processes (progradational stacking pattern) as shown in the parasequence stacking pattern of the wells. The transgressive system tract unit of this sequence is capped by the 31.3-Ma MFS (Ru-2-Uvigerinella-5) marker.

SEQ 4 which is approximately 550m thick. It is bounded by the 27.3Ma and 29.3Ma SBs, respectively. The sequence was deposited within the inner to the middle neritic paleo-depositional environment. The transgressive system tract unit of this sequence is capped by 28.1-Ma MFS (Ch-1-Bolivina-27) marker.

SEQ 5 is approximately 110m thick. It is the youngest sequence in the study area. The transgressive system tract unit of this sequence is capped by 26.2-Ma MFS (Ch-2-Alabammina-1) marker.

Conclusion: Chronostratigraphic surfaces matched with P&F zones revealed that the study area falls within the Late Eocene to Late Oligocene age. Five sequences and three systems tracts of type 1 third order depositional sequence were recognized. The alternation of sands of the LST and HST will offer potential reservoir while the shale units of the TST will make good seal/source rocks. The correlations reveal a normal delta progradation with continuity of the facies along strike direction. It is hoped that the study will contribute to the growing knowledge of sequence stratigraphy in solving the complexities of hydrocarbon exploration in the Niger Delta.

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