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Lithofacies and Environmental Analysis of Reservoir Sandstones in the "ABOM" Oilfield of Eastern Niger Delta, Nigeria

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Authors' contributions

This work was carried out in collaboration among the two authors. Author OOJ carried out the study under the supervision of author MIO. Both authors designed the manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

Facies of part of the Coastal swamp depobelt was analyzed using well log. Electrofacies was defined based on well log signatures. The defined facies were inter-related to define a facies association. The facies association were related to deltaic depositional cycles. 10 of such facies association or deltaic cycles were seen in the interval studied. The facies association or deltaic cycles have a different composition of facies related to the level of preservation of the components of the association. The component of the facies association seen include marine clay facies, lower shoreface facies, upper shoreface facies, prograding mouth bar facies and fluvial facies. The marine clay facies underlie each facies association and the channel / prograding mouth bar cap the association where it is preserved. The lower shoreface facies, upper shorefacies, prograding mouth bar and fluvial facies form the Reservoir sandstones. The identified facies association was seen to be repeated in the interval studied though with different composition. This reflects different deltaic depositional cycles with different component of facies due to the prevailing depositional processes occurring at the period of deposition and those affecting the deposit of the cycles after deposition. The arrangements of the different components of the facies within the facies association will help in the prediction of reservoir sand bodies in any deltaic depositional cycle.

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1. INTRODUCTION

The idea of sedimentary facies analysis, aid to understand the events and influences which lead to the formation of sedimentary rock deposits Reading [1]. Gressly in 1838, first used the expression facies Reading [1]. A facies refers to any mass of rock having definite distinctiveness that distinguishes it from a different mass of rock. Such features reveal a specific event, an arrangement of setting in a particular sedimentary environment during deposition of the sediment. Such characteristics also help in comparing the facies with others and help to foretell the existence of economic deposit Reading [1].

Facies could be expressed from lithological perspectives as lithofacies, in which importance is on the observable and substantive properties of the rock such as grain size, shape, fabric, its appearance in visible light, structure, and what it is made up of. When a rock unit is defined considering its flora and fauna make up, then it is termed a Biofacies Reading, [1]. Electrofacies deals with rock units differentiated on the basis of their response to electric and wireline logs. To know the environment where a facies is deposited from wireline log, cores or outcrops, one need to relate the identified facies to the physical as well as the biological processes that generate it Anderton R, [2]. This is an action-reaction mechanism from which the depositional environment in which the processes occurred might be deduced Coleman JM, [3].

This study is aimed to identify the different facies in part of the coastal swamp major depositional period (depobelt) of the Niger Delta Basin, linking them together as a group of facies into facies association that defined a deltaic depositional cycle. The depositional processes generating the facies were also inferred and the environments of the Reservoirs Sandstones facies were deduced.

1.1 Geological Setting

The Niger Delta geology resulted from the third sedimentary cycle within the Benue Trough Stauble and Short, [4]. The first cycle began in Albian and ended with mild folding during Santonia. The second cycle involved the generation of the Proto Niger Delta basin (Anambra basin and Afikpo syncline) rocks Momta PS, Essien NU, [5] and ended with a marine transgression in Paleocene during which the Imo shale was deposited. The third cycle beginning in Eocene and continuing to recent produces the rocks within the Basin Stauble and Short, [4]. Fig. 1 shows the map of the proto Niger Delta including the Cenozoic Niger Delta Basin rocks.

Recent studies of the rocks within the Niger Delta sedimentary rock types and sites of sediment accumulation, has generated a model that correlates changes in rock types to changes in depositional processes within a great power, majorly wind generated surface water movements (wave) controlled, builded bow to lobe shape humid delta Reiijer, [6]. These processes: fluvial, tidal, waves that generates longshore drift, have produced three major rock units: Benin Formation, Agbada Formation and Akata Formation.

2. MATERIALS AND METHODS

Thirteen well logs were used for the study. The logs are gamma ray, density, neutron, resistivity, sonic.

Facies were identified from well logs, gamma ray, density, neutron, resistivity. The lithology of each facies or lithofacies was first determined principally from gamma ray, neutron and density combination Dresser Atlas, [7]. A Baseline for one lithology for example, shale was used as a reference to identify shale and same for sand. A facies was identified from changes in log signature called trend. A log trend is a continuous variation in the amount of measured properties either increase or decrease within an interval. The trend can be within the range of a metre (3 feet), when they are related to bedding planes, tens of metres (30 feet and above) when they are related to sedimentary facies and hundreds of metres (328 feet and above) when they are related to large scale basinal events Rider, [8]. Gamma ray trend pattern for different facies have been identified see Fig. 2, trends of gamma ray in the wells used were compared with identified trends which have defined facies in other areas and these were used to identify facies in the study area.

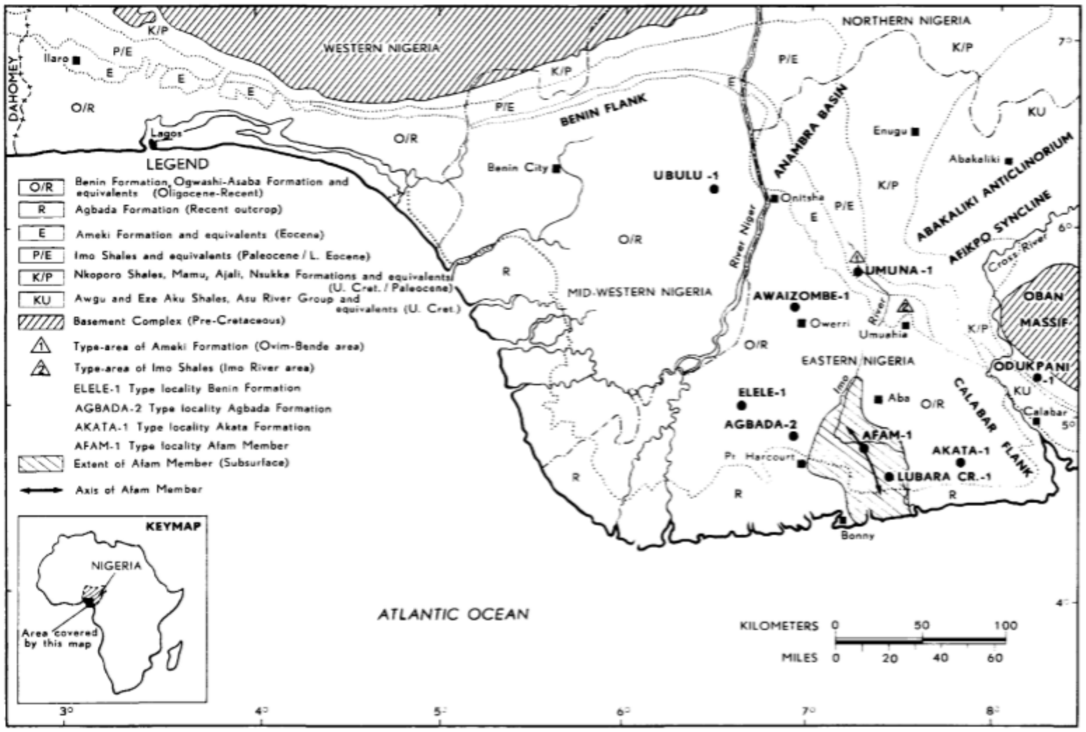


Fig. 1. Map (geologic) of southern Nigeria showing rocks of Anambra Basin and Tertiary Niger Delta basin with type section of subsurface units (Adapted: Short and Stauble)

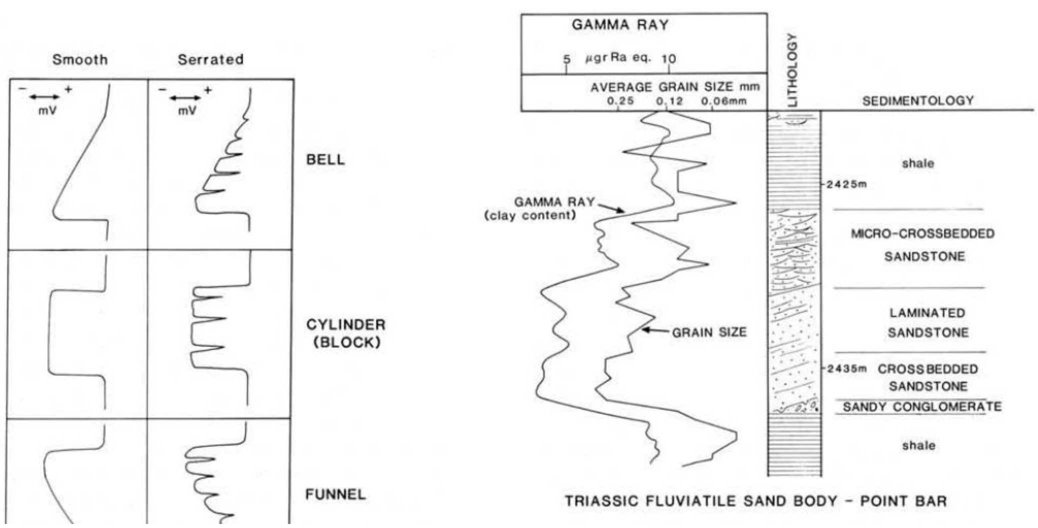


Fig. 2. Gamma ray trend forms grouped into shapes, defining particular facies e.g, the Point Bar facies. Adapted from M. Rider, 2002

The rock types were determined from analysis of the logs based on their operational principles. Depositional processes generating each of the identified rock types were determined from features produced by the processes on the rocks Momta PS, [9]. Features such as grain size trend which is normally unique to a particular process and always different from one facies to another was used to define the processes generating the rocks Momta PS, Essien NU. [10].

Since grain size have relationship with clay / shale content which is measured by gamma ray log, trends in grain size were determined from the gamma ray trend as either fining upward or coarsening upward, which is unique to different depositional processes.

3. RESULTS AND INTERPRETATION

The facies seen in the study include, marine clay facies, lower shoreface facies, upper shoreface facies, prograding mouth bar facies and fluvial facies.

3.1 Facies

3.1.1 Prodelta or marine clay sub facies

This portion of the facies association consist of marine clay which have formed shales. It display a high gamma ray reading and the lithology from the gamma ray, density and neutron log is shale. Occasional minor silt and very fine sand lenses may be seen in some cases The density log also support this. It occur at the base of the facies association, and thickness varies from one well to another. The predominance of the shale show that they are deposited from suspension fall out processes in shallow marine to marine environments Momta PS, Odigi MI, [11]. The lenses of silt and very fine sand within the shale may represent catastrophic event that lead to their deposition such as storm induced turbidity current Prince Suka Momta, Jonathan O. Omoboh, Minapuyi I. Odigi. [12].

3.1.2 Lower shoreface sub facies

This facies lies above the marine clay. It consists of shale at bottom with silt and very fine sand to fine sand on top. The gamma ray log, the density and neutron log show a change in lithology from shale to sand in a gradual other. The base of the facies unit is gradual and typically displays a funnel shape which show a coarsening upward sequence. Thickness varies from one well to the other, but seem to decrease towards the south. Imprint of tidal processes is seen in form of clay lenses and thin beds within the facies. The sand represents deposition from bedload while the shale lenses represent suspension fall out during flood tides. This facies underlies the upper shoreface unit above and have a gradational contact with the facies above it. This shows a progressive change in depositional processes and thus environment Middleton GV, [13].

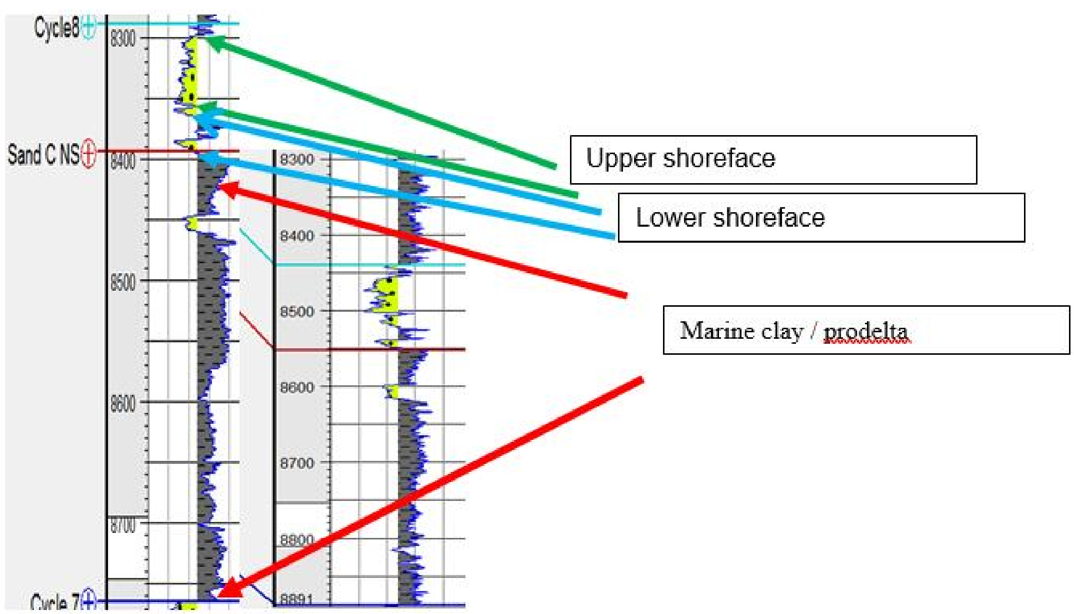


Fig. 3a. Facies association showing the different subfacies seen in the wells of the study area

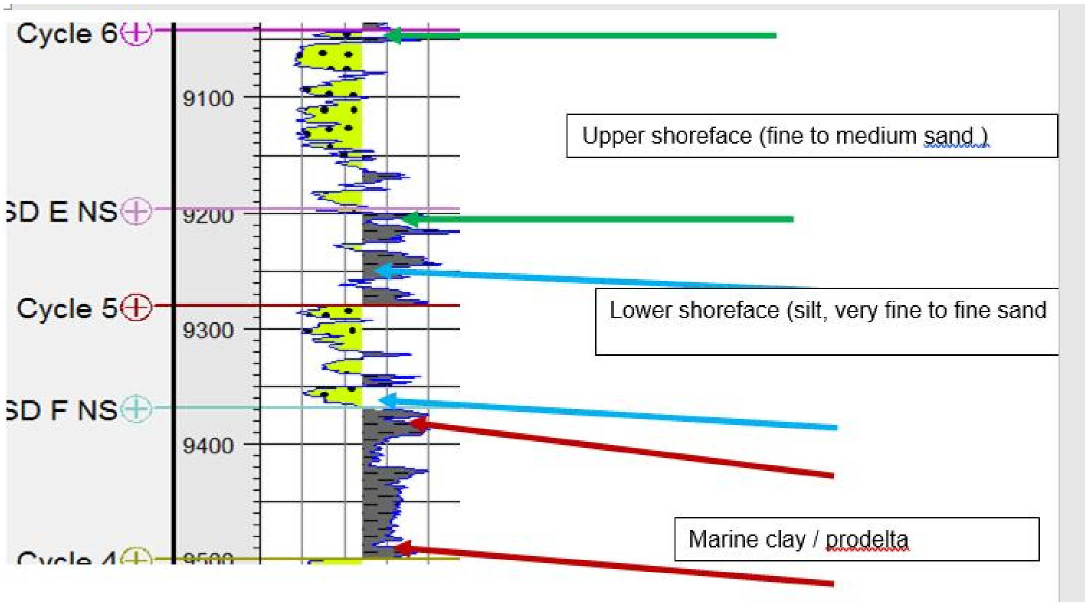


Fig. 3b. Facies association showing the different subfacies seen in the wells of the study area

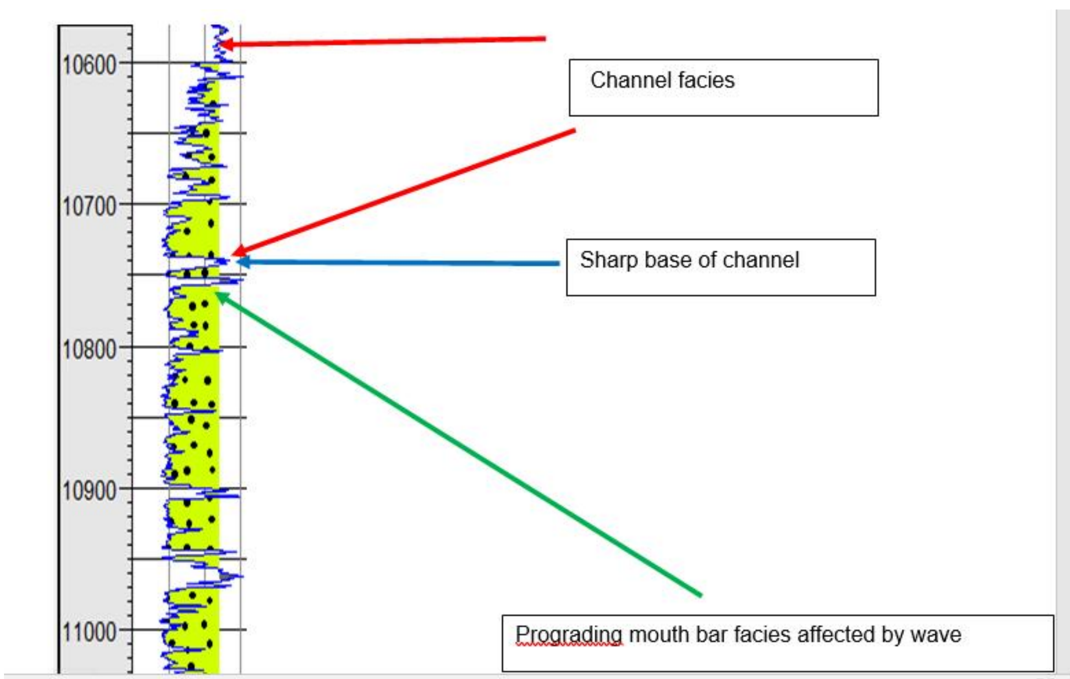


Fig. 3c. Facies association showing the different subfacies seen in the wells of the study area

3.1.3 Upper shoreface sub facies

This facies always occurs at the upper part of the facies association. It consists of fine to medium grain sand as seen from the lower gamma ray values; shows a coarsening upward trend which reflects a decrease in clay or shale content. This reflects an increase in depositional energy overtime. Deposition of the sand is from bedload transport, while the sometimes associated shale is from suspension fall out due to short leave increase in water depth which reduces transport velocity greatly at the point of deposition Francisca E, Oboh Ikuenobe, Chuka G, Obi

Carlos A. Jaramillo, [14]. The thickness varies from well to well but seems to increase northwards. It shows a gradational basal contact with the lower shoreface below and gradational to sharp contact with the marine clay unit that lies above it. The sometimes sharp contact of the marine clay above it shows the erosive effect of the transgressive phase which shift deposition of coarse sediment landwards relative to the position of the facies and cause fine materials to be deposited on the original coarse sediment of the shoreface Momta PS, Odigi MI [15].

3.1.4 Prograding mouth bar subfacies

This facies did not occur in all the facies association, but where it occurs it shows a channel features capping it see Fig. 3c. It has a gradational base, alternation of funnel, cylinder and bell shapes, an upward increase in grain size, upward decrease in clay / shale content. This reflects a coarsening upward unit (the funnel shape) and a fairly uniform argillaceous content and or grain size (the cylinder shape). This reflects deposition from bedload transport which was modified by wave processes winnowing away fine particles and removing the argillaceous portion and thus the fairly uniform grain size and thus, cylinder log shape. The sharp base seen within the interval reflects erosional effects of distributary channel that overlies the mouth bar see Fig. 3c above.

3.2 Facies Association and Deltaic Cycles

The facies association consist of marine clay at the bottom as evident from the high gamma ray reading, this was followed by marine clay with silty and very fine sand lamination (silty/ sandy clay), which was then followed by very fine sand to fine sand with minor clay/ shale laminars. (shaly sand), medium to coarse sand cap the facies association in most cases. The whole arrangement shows an overall coarsening up sequence, in which the coarse portion in some cases represent the identified reservoirs see Fig. 3 above. This type of facies arrangement was seen to be repeated within the paralic section of the study area. In some cases, the coarse portion may be thicker while the marine clay and the fine portion may be thicker at some other cases. The following subfacies were identified within the facies association: prodelta or marine clay facies, Lower shoreface subfacies, upper shorefaces subfacies, prograding mouth bar which were already described above. This type of facies association is seen repeated within the Agbada interval of the study area.

An Active constructional phase of delta out building produces deltaic deposits that prograde seawards producing a coarsening upward vertical succession of facies as delta front sands advance seawards on prodelta silt and clay Boggs, [16]. This is often interrupted by major and small scale changes that stop the progradation of the delta. Major changes can result from relative sea level rise that may stop the progradation of the delta growth and bring about transgressive phase of deposition as the shoreline advances in a landward direction, thus growth of delta tends to be cyclic Boggs, [16].

The paralic section of the Recent Niger Delta, that is the Agbada formation have been identified to be made up of considerable records of deltaic depositional cycles, each cycle having depth ranging from 15 to 100m Weber, [17]. A full cycle usually consists of a narrow fossiliferous transgressive marine sand followed by an offlap system, made up of marine shale, followed by laminated fluviomarine barrier foot deposit Weber, [17]. Barrier bar and or river deposited deposit could follow prior to the closure of the cycle by marine transgression Weber, [17]. The barrier foot sediment should correspond to the shorefaces while the barrier bar should correspond to the mouth bar and the river deposited sediments the distributary channels. The makeup of every cycle in a well is often a function of the location of the well relative to earliest shore Weber, [17]. The higher component of a lot of cycles (distributary channel, mouth bar and even upper shoreface) have been removed through scouring by the following transgressive period of deposition Weber, [17]. About 10 of such deltaic depositional cycles, serving as facie associations were identified in the study area Fig. 4. Cycles occurring towards the northern part seem to have more of the sandy facies: upper shoreface and lower shoreface. The marine clay facies becomes thicker towards the southern end.

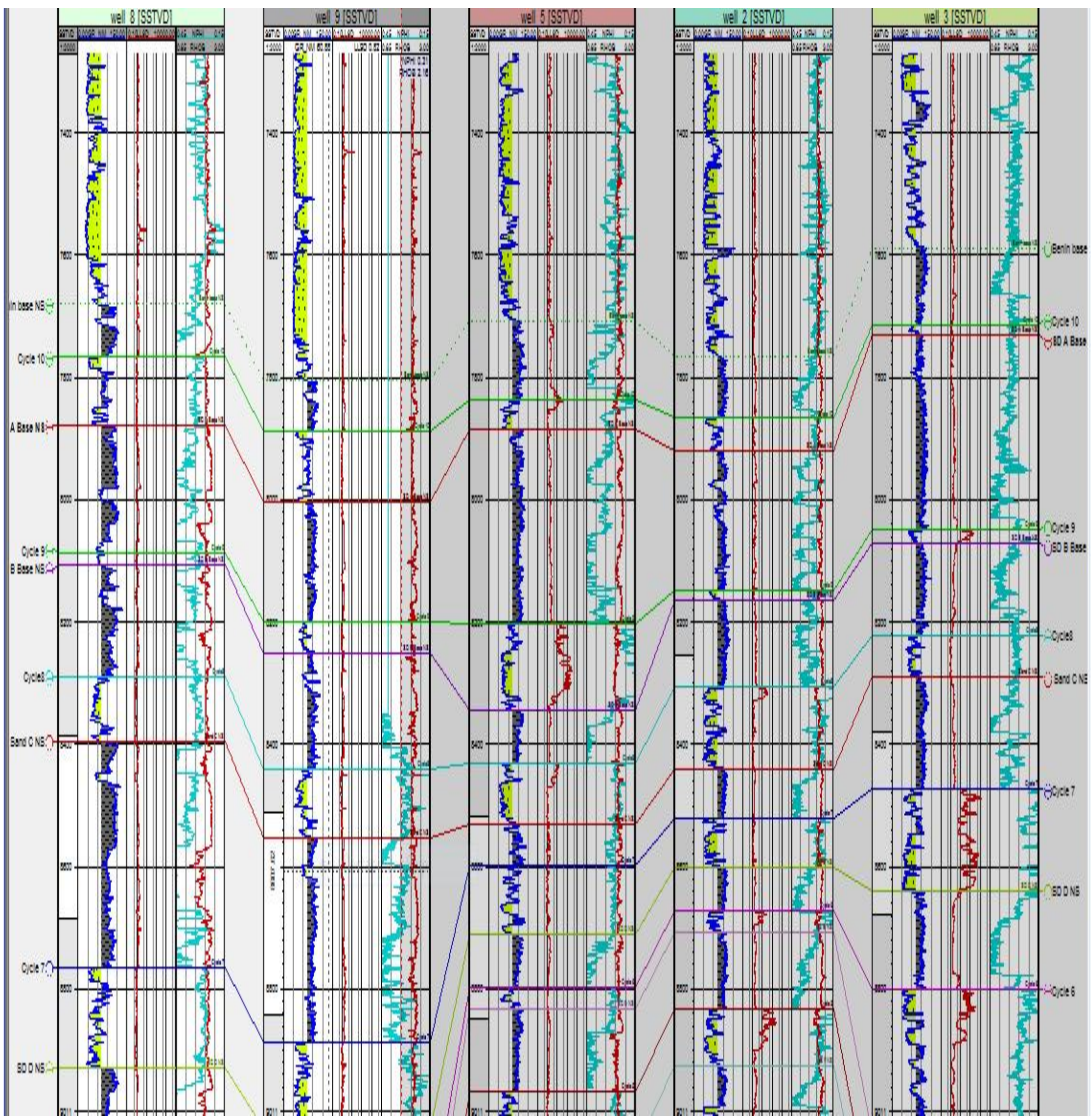
4. DISCUSSION

4.1 Depositional Environments of the Sand / Sandstone Facies

The Reservoir facies within the facies associations are the lower shoreface facies, upper shoreface facies, prograding mouth bar facies and Channel facies.

Shoreface is a region of the marine environment that lies between low tidal marks and the depth to which fair weather wave affects sediments at the bottom. This implies that tides and waves will affect shoreface facies. The lower shoreface will have lesser effects of both Ntokozo Malaza, Kuiwu Liu, Baojin Zhao, [18].

The lower shoreface followed the marine clay facies seen in the facies association and the lower shoreface was followed by the upper shoreface. The prograding mouth bar is the deposit at the mouth of a river where it enters the ocean or sea. The interaction of the transporting river and the ocean or sea water lead to the deposition of the mouth bar Ramr M, [19]. The upper shore faces will lie basinward of mouth bar facies Ezenwaka KC, Obiadi II, Nwaezeapu VC, Irumhe EP, Ede DT. [20]. This shows that these environment lies adjacent to each other during deposition according to Walther's law of facies succession Middleton GV, [13]. This is due to the graduation contacts between the marine clay, lower shoreface, and upper shoreface. The sequential arrangements of each component of the facies association and thus of their environments coupled with the repeated nature of the facies association (deltaic cycles), will make the prediction of reservoir facies possible in any deltaic environment of deposition.



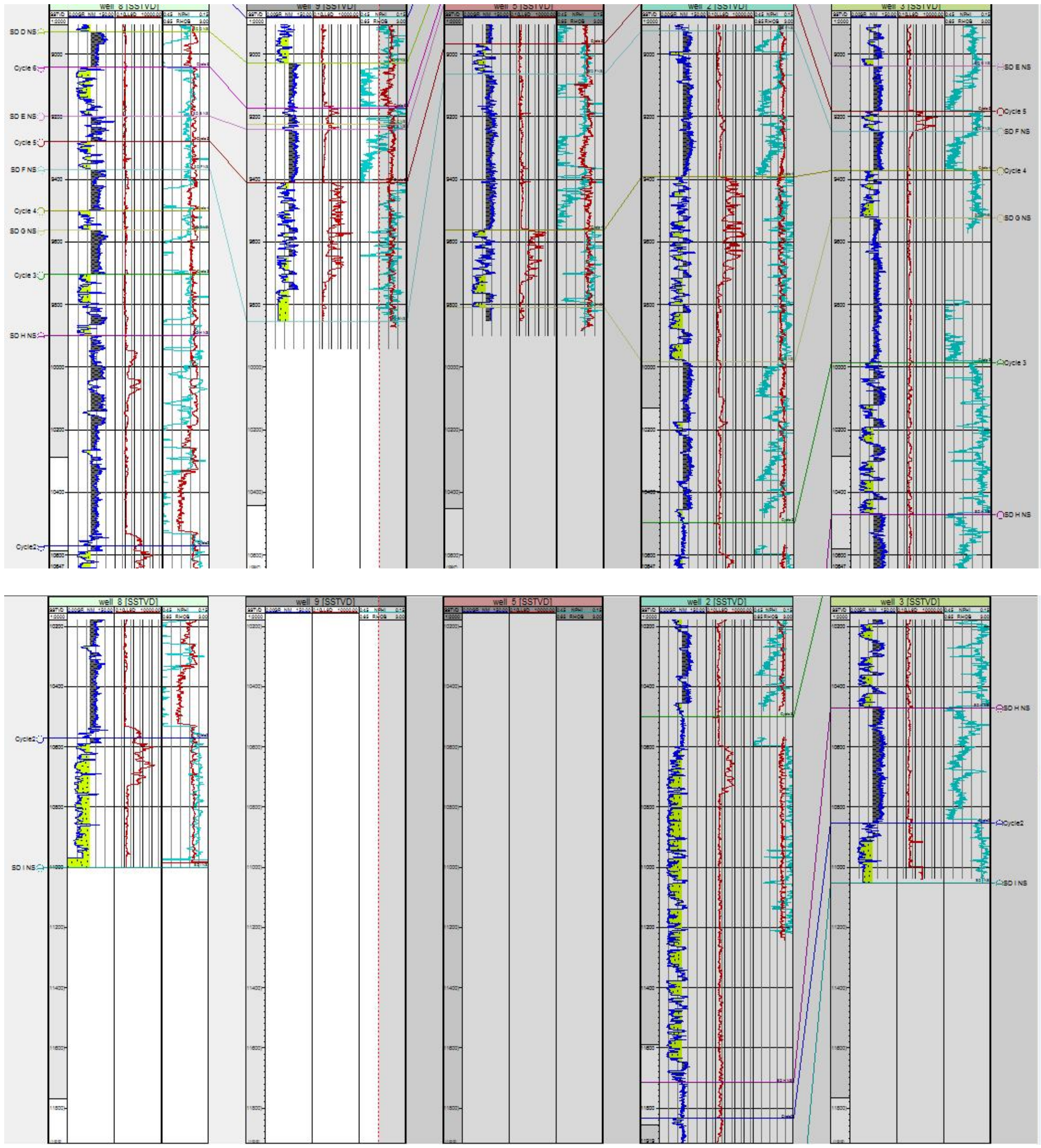


Fig. 4. Correlation panel along the north – south direction showing deltaic depositional cycles

5. CONCLUSION

Marine clay, lower shoreface, upper shoreface, prograding mouth bar, channel facies were analysed in the studied portion of the coastal swamp depo belt. These facies occur together to form a facies association in which the marine clay always occur at the bottom followed by the lower shoreface then upper shoreface then prograding mouth bar and capped with channel facies; where all the components of the facies association exist. The facies association was seen repeated in the study interval and were interpreted to represent deltaic depositional cycles. Ten of this cycle was seen in the interval studied each with different composition related to the position of ancient shoreline. The sequential order and positioning of the lower shoreface, upper shoreface, prograding mouth bar within the facies association and repetitive nature of the facies association will enhance the prediction of reservoir sandstones in any deltaic depositional environment. This study will therefore help in the prediction of reservoir sand bodies in any deltaic depositional environments.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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