PETROLEUM STUDIES AND RESERVOIR ATTRUBUTES OF THE "MM" SAND,'OLO, FIELD, NIGER DELTA, NIGERIA

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This research work focuses attention on the Reservoir Characterization of a hydrocarbon bearing sand in 'Olofield of the Niger Delta. The environment of deposition is examined and the type produced as a model of the sub-surface reservoir. To achieve this, an integrated analysis of cores from wells, as well as biostratigraphic data and wireline logs of the MM sand were used for the study. The MM sand of study comprises one major depositional sequence. From the petrophysical study carried out through use of composite logs, amalgamated sand is found to be more porous and more permeable than the tidal channel. Core analysis revealed the existence of ten lithofacies. These lithofacies are grouped into facies association in a vertical sequence with a genetic significance using primary

INTRODUCTION

MM sand comprises multi-storey sand bodies and heterolithic mixture of sand shale. These sand bodies have good reservoir quality, while the heterolithics have reservoir quality and act as baffles to vertical flow of hydrocarbon. Thus, this cause production problem in the MM sand. The research work is intended to unravel the sequence stratigraphy of the MM sand through the existing approach of use of cores and wireline logs.

A reservoir rock may be defined as a formation that has the capacity to store fluid and have the ability to release the fluid when tapped as a resource (Etu –Efeotor, 1997). Such fluid can be oil, gas or water. Therefore, the exploration for oil and gas in the Niger Delta is actually, the search for hydrocarbon bearing reservoir which is either carbonates or clastics (sandstone and conglomerate). Studies by geologists such as Short and Stauble (1967), Weber and Daukoru (1975), Doust and Omatsola (1990), Reijer (2011), etc reveal that the reservoir rocks in Niger Delta are mainly sandstone. The exploration and development of a reservoir requires reasonable understanding of its occurrence and morphology. Sandstone occurs in different sedimentary environments, which is a part of the earth's surface that is physically, chemically and biologically distinct from adjacent terrains. (Selley, 1985). The variation in sedimentary environments may be attributed to differences in energy levels, flow velocity and climate, resulting in differences in morphologies and qualities of sandstone reservoir. The environment of deposition of sediment is the sum of the physical, chemical and biological condition under which it was deposited. These conditions are recorded in the form of sedimentary facies, which is a mass of sedimentary rock that can be defined and distinguished from others by observed rock properties such as lithology, texture, sedimentary structures, geometry, fossils and paleocurrent pattern displayed in sequence on core samples and some in wireline logs. From observed succession of these rock properties in sandstone, a judgment can be made of the transporting medium, the condition of flow at the time of deposition, the nature of the depositional site and then qualitatively predict the quality of the reservoir sand body. According to Tyler et al. (1991), average recovery efficiency of oil could be tied closely to depositional environments and recovery mechanism. Weber and Daukoru (1975), Evamy (1978), Ekweozor and Okoye (1980) have reported in their works on Niger Delta reservoir rocks, that the quality of the sandstones as initially deposited is a function of the source area, the depositional processes and the environment in which the deposition takes place. To advance this knowledge, the depositional characteristics of MM sands of "OLO" field, Niger delta were studied.

AIM AND OBJECTIVES

The objectives of the study are: To provide a detailed Reservoir Characterization of the reservoir (MM) sand.

Ascertain the permeability and porosity values and evaluate the reservoir potential of' MM sand and to reconstruct the environment of deposition and provide a depositional model suitable for the reservoir sand.

Niger Delta Geology

The stratigraphy of the Niger Delta is intimately related to its structure. The development of each being dependent on interplay between sediment supply and subsidence rate. Short and Stauble (1967) recognized three subsurface stratigraphic units in the modern Niger Delta. The delta sequence is mainly a sequence of marine clays overlain by parallic sediments which were finally capped by continental sands.The stratigraphy of Niger Delta Basin are as follows:

Benin Formation: - The formation comprising over 90% sandstone with shale intercalations extends from the west across the entire Niger Delta area and southward beyond the present coast line. The thickness though variable is estimated at about 6000fts. It is coarse grained, gravelly, poorly sorted, sub-angular to well rounded and bears lignite streaks and wood fragment. The formation is characterized by structural units such as channel fills, point bars etc which indicate variability of the shallow water depositional medium. The Benin formation with very little hydrocarbon accumulation ranges in age from Oligocene to Recent.

Agbada Formation: - The formation is a sequence of sandstones and shales with sandstone dorminant in the upper unit and thick shales in the lower unit. It is very rich in microfauna at the base decreasing upwards suggesting an increase in the rate of deposition at the delta front. The grains are coarse and poorly sorted indicating a fluvatile origin .The Agbada formation covers the entire subsurface of the delta and may be continuous with the Ogwashi-Asaba and Ameki formations of Eocene- Oligocene age. It is over 10,000ft thick and are the major hydrocarbon bearing unit in the delta.

Akata Formation: - The formation underlies the entire delta and forms the lower most unit. It is a uniform shale development consisting of dark grey sandy, silty shale with plant remains at the top. The Akata formation is typically overpressured and believed to have formed during lowstands when terrestrial organic matter and clays were transported to deep water areas characterized by low energy conditions and oxygen deficiency (Statcher 1995). It is over 4000ft thick and ranges in age from Eocene to Recent and is believed to have been deposited in front of the advancing delta.

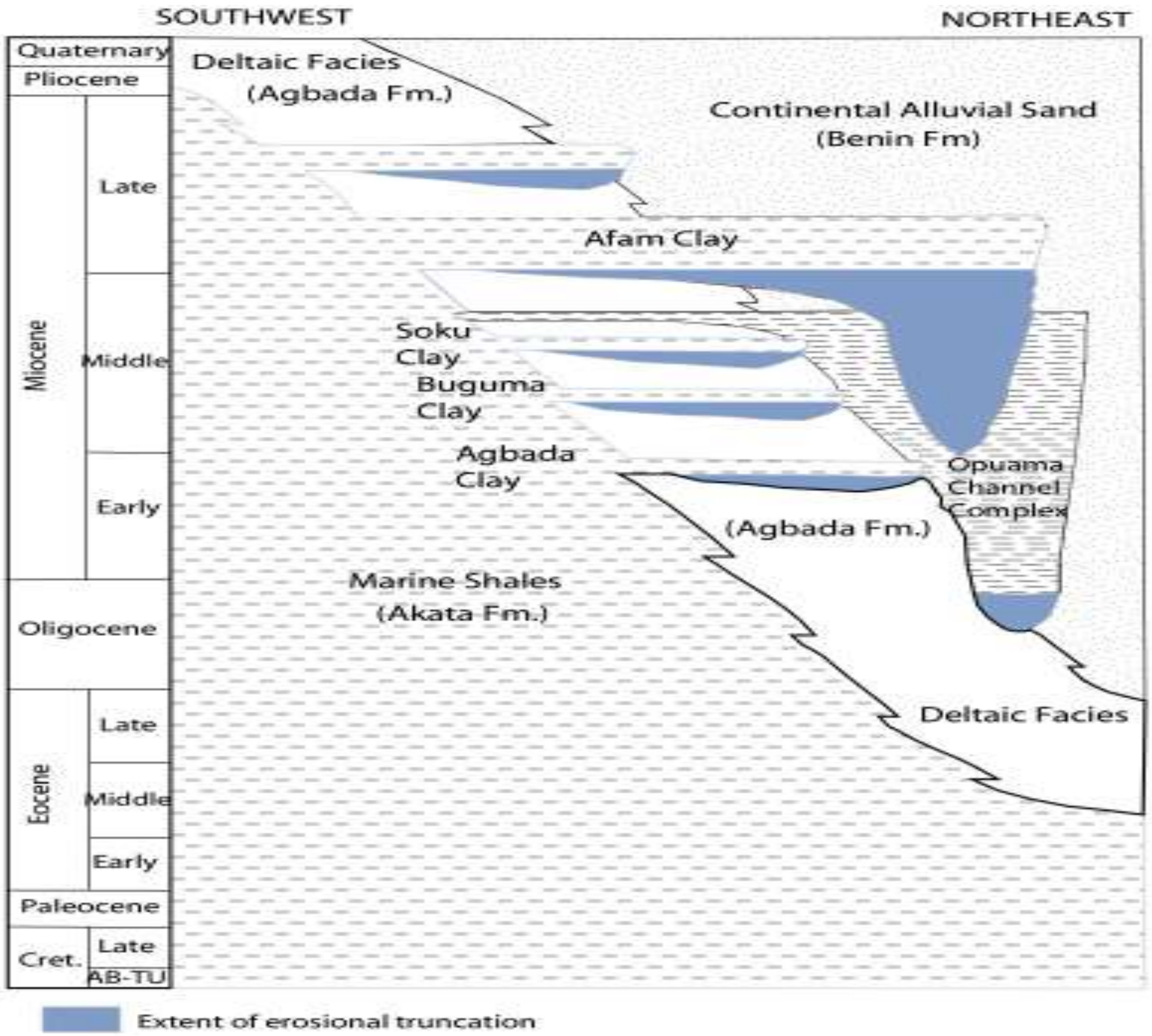

Figure 1 : Stratigraphic column showing the three formations of the Niger Delta. (*Adapted From: Tuttle et al, 1999*).

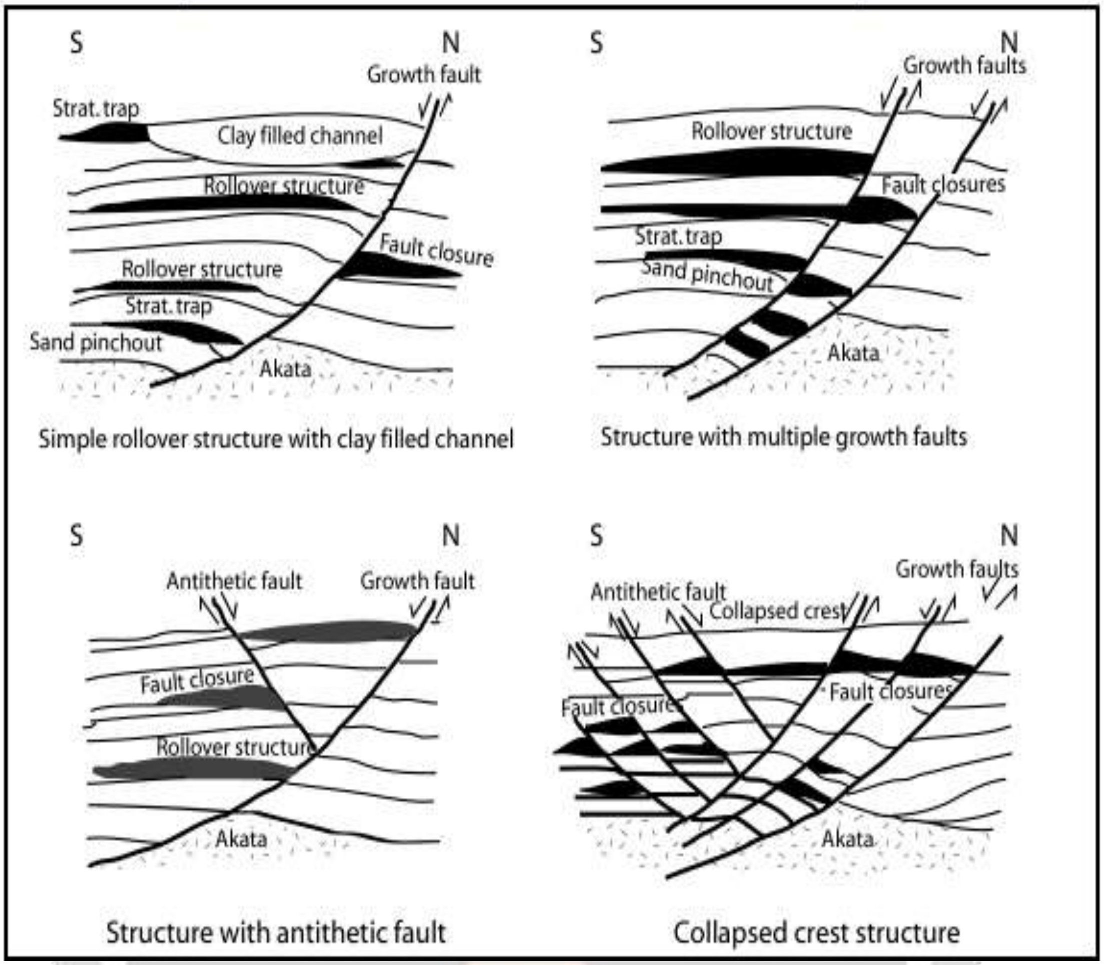

Figure 2: Major structures and associated traps in the Niger Delta.
(*Modified from: Doust and Omatsola, 1990; and Stacher, 1995*).

Location of the Study Area
The hydrocarbon bearing (MM) sand is located in the 'OLO' field of the central depobelt of the Niger delta. The field is very close to the Nun river, about 110 west of Port Harcourt. It lies between latitudes 50 and 6° N, and longitudes 60 and 7° E.

METHODOLOGY

There are three methods of study used in the analysis of the MM sand. They are core description, the use of wireline logs and biostratigraphic data interpretation.
A. Core Description:
The analysis of the reservoir sand involves the use of integrated cores from the well taken from the top to bottom of the MM sand. The total length of cores described for the well are about 292ft. Core is described in terms of the primary sedimentary structures, bioturbation, grain sizes, sorting, colour, diagenetic processes as well as lithology.

B. Primary Sedimentary Structures
Pettijon and Potter defined primary sedimentary structures as those formed at time of deposition or shortly thereafter and before consolidation of the sediments in which they are found. These sedimentary structures are as a result of physical, chemical and biological processes occurring in an environment. Based on the processes of formation of these sedimentary structures, lithofacies are classified.

C. Wireline logs

Use of wireline log data is to guide and aid the sedimentological interpretation of the cored sequences employed. In order to ascertain the porosity and permeability values of the reservoir sand, a composite log is used. These include gamma ray log, bulk density log and resistivity log.

RESULTS/INTERPRETATION

Core Result

Core results of well indicate that the lithofacies are commonly sandstone/shale alternations or sequences. Some of the parameters used in identifying the lithofacies are as follows:

(1) Grain Sizes: Visually, the grain size distribution falls within the range of very fine to coarse grain hence, bedding surfaces are recognized mostly by abrupt vertical changes in sizes and sometimes gradational changes occur. One of the intervals where abrupt vertical changes occur is seen in well 6 at a depth of 13356ft. Generally, there is mostly a decrease in grains sizes with an increase in depth from the lower half of the reservoir sand as seen in the well at a depth

of (13230-13335) ft.

(3) Colour: There are varieties of grey colours seen while examining the cores. Colour ranges from light grey to darkplategrey. For example, at the distal end of the two cored wells, the colour is found to be dark grey shale which is anbindication of the presence of organic matter.

B. Lithofacies Description

Various kind of sedimentary structures are seen through physical examination of cores from well. These include, planar cross bedding, current ripple marks, lenticular bedding, rootlets, hummocky cross stratification, reactivation surfaceBioturbation Structures and many more. These inorganic primary sedimentary structures are produced as a result of interactions between the physical and biological characteristics of the sediment and the fluid, gravity, as well as the hydraulic environment.

Lithofacies are identified based on core description and log shape of the reservoir MM sand in 'Olo' field.

Individual lithofacies are composed of different types of sedimentary structures and may be distinguished by the presence of bedding units with a characteristic sedimentary structure, a limited grain size range, a certain bed thickness, perhaps a distinctive texture or colour.

Planar laminated sandstone. The lithofacies, planar laminated sandstone comprises fine to medium sand particles. Itis moderately to well sorted, grey in colour and consists of planar grain lineation of coarse and medium grains which form laminae on foresets (Plate 1). The lithofacies is about 2cm to 4cm thick, it has an erosional relationship withoverlying lithofaices coarse grained cross bedded sandstone and gradational relationship with underlying lithofacies wave rippled sandstone. However, very fine grains of mud are conspicuously absent and there is no presence of bioturbation activities in this lithofacjes. In essence, it is an indication of high energy or shallow marine environments

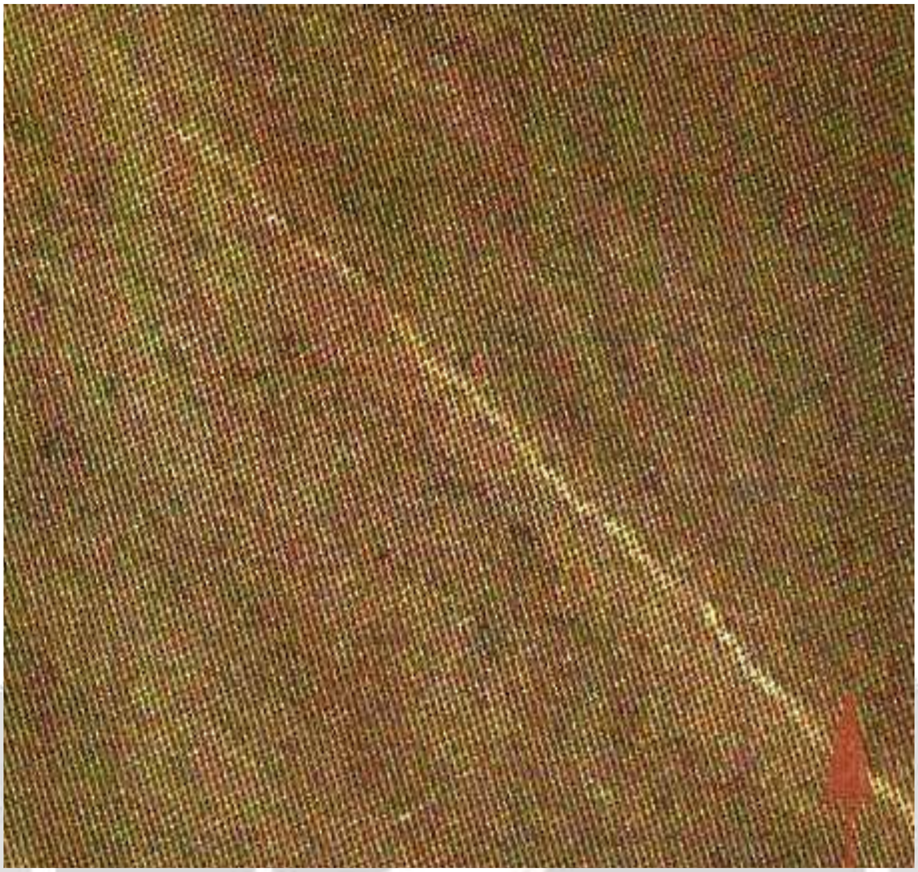

Plate 1- Planar laminated sandstone

Current-rippled sandstone. The lithofacies consists of fine to medium grain sandstones with some coarse grain materials found at the base. It is moderately sorted. There are no wavy beds and has a clay content but low angle crossbedsexist. The rippled sandstone is draped by wavy, dark grey mudstone which is assymetrical with a gentle slope, an indication of current direction. The lithofacies contains a sporadic bioturbation traces though tracesPlanolites and ichnofacies is common with scanty Skolithos traces. This type of lithofacies is likely to occur in fluvialor shallow marine environment. Hence, tidal channel or tidal flat are the likely potential origin of this facies.

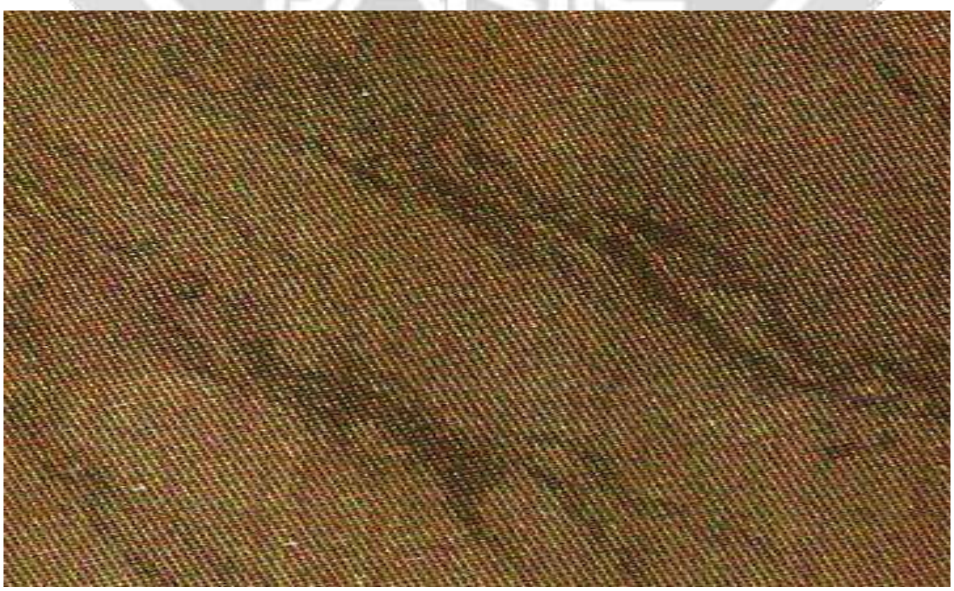

Plate 2-Current rippled sandstone

3. Bioturbated sandstone. Sandstones in this lithofacies constitute very fine- to- fine grains. Though, medium gains are encountered sporadically. It is well sorted with discontinuous carbonaceous laminae. There is also very little clay content with the absence of primary sedimentary structures as a result of intensive Bioturbation activities. Furthermore, the dominance of interpenetrating burrows of Ophiomorpha nodosa and Planolites are identifiable together with rare fossil shell remains . The presence of the aforementioned ichnofacies characterizes the influence of tidal or stressedestuarine environment. Also, the intensive bioturbation is an indication of lower shore face environment.

4 Fossiliferous Sandy heterolitlih. This sediment is observed in fine to very fine grained sandy strata. There isabundant shells debris which makes the lithofacies to be poorly sorted and is a major characteristic of the lithofacies.The clay content is high and could be noticed from the greyish-dark colour of the sandy heterolith. The lithofaciesconsists of climbing ripple lamination. Bioturbàtion activity is moderate to high, though the trace fossils encountered inthe lithofacies include Ophiomorpha and Skolithos traces which occur sparingly. The very fine- to-fine grain size is an

indication that it is deposited under low energy condition. The abundant shell debris shows the presence of shoreline setting while the trace fossils indicate shallow marine environment.

C. Reservoir Characterization

The reservoir (MM) sand is composed of some good quality sandstones interbedded with mudstones. These mudstones act as permeability barriers to the vertical flow of hydrocarbon for this reservoir. The depositional sequence

in the MM sand is differentiated by change in grain sizes marked by mudstone facies. However, the occurrence of' sandy heterolith in some parts of the reservoir could cause a differential flow in the lithological units. These lithological units may be in pressure communication with each other as a result of density contrast of the depositional environment.

From petrophysical property of the MM sand obtained. Porosity and permeability values of the MM sand are calculated using wireline logs. A very high decrease in porosity and permeability is an indication of low sand/shale ratio in the environment of deposition. High water fraction is an indication that the environment is not a potential for oil. From the gamma ray log of the sand, the zone shows a gradation with the shelf mud. Hence, it is inferred to be part of the basal area (bottom seal) of the sand or source of hydrocarbon. Finally, the rank of the interpreted depositional environments in terms of porosity and permeability from the best to the poorest is as follows: amalgamated channel, tidal channel, tidal deposit, upper shoreface and lower shoreface.

1) Petrophysical properties of MM Sand, . Plot of permeability against porosity is essentially a straight line in semi logarithmic paper. There is a high concentration of these petrophysical values as porosity and permeability increase. However, from the mathematical relationship, permeability increases with increase in porosity. Environmental and depositional factors influencing porosity such as grain size distribution, bioturbation and diagenesis also influence permeability and often there is a relationship between the two. Typically, increase in permeability is accompanied by increase in porosity. The relationship varies with Formation and rock type and reflects the variety of pore geometry present. Constant permeability accompanied by increase in porosity, indicate the presence of more numerous but smaller pores. Post depositional processes in the sand including compaction and cementation result in shift to the left of the permeability-porosity trend line. The MM sand is composed of intercalation of sand and shale. The shale is probably composed of authigenic and detrital clay minerals which are often found in lithofacies such as bioturbated sandy heteroliths (SMb). These minerals can greatly influence porosity and permeability as well as Formation productivity. The degree of influence depends on the type of clay present, it's morphology, it's location within the system and to a lesser extent, it's relative abundance.

Most part of the MM is inferred as stacked channel using gamma ray log of the sand from well. In the description of the petrophysical properties of this depth range, there is a high resistivity value, low bulk density, very high permeability as well as very good porosity values. Taking the mean of the sum of the porosity and permeability values in the stacked channel of petrophysical properties, then the average porosity and permeability is 24 % and 1330 MD respectively. Furthermore, the stacked channel shows a very high oil fraction close to one and a water fraction close to zero. The high resistivity value of this part of the reservoir with respect to the tidal channel described earlier is attributed to the fact that, it has a lesser clay content than the tidal channel. This may be as a result of larger grain sizesand iion in the environment of deposition. Example is seen from the lithofacies containing cross-bedded sandstones and planar laminated sandstone . However, a very high oil fraction with little or no water fraction in this environment relative to other parts of the reservoir makes it an ideal part to explore in the sand more

than other Sections of the reservoir. The poor petrophysical properties in this part of the reservoir relative to the stacked channel environment is attributed to the clay composition or sandstone inter-bedding with mudstone. The point where oil fraction mixes with water fraction is inferred to be the oil/water contact (OWC). Unequal variation in the porosity and permeability is an indication of sand/shale intercalation in this part of the MM sand. Therefore, the mode of deposition in the environment is through bed load transportation and suspension fall-out. Thus, the characteristic of the lithofacies with respect to the sand/shale ratio and grain size distribution affect the petrophysical properties as well as the depositional environment. Example, fine to very fine grain particles are deposited mostly in aquiet environment while coarse grain materials are properties of fluvial to wave dominated shallow marine setting.
Below the mm in the reservoir, that is, at a range of 12460 to l2500ft, core porosity and permeability decrease more than that of the tidal deposit above. Resistivity decreases while bulk density increases. Water fraction exceeds the oil fraction. Also at a depth range of about 12328 to 12350ft, porosity and permeability show unequal variation downward in the MM reservoir sand. Resistivity shows a variable signature as well as bulk density downward. In the plot, oil fraction co-exists in equal proportion with water fraction and at 12350ft, oil fraction mixes with water fraction, this part of the reservoir coincides with the tidal deposits.
Due to progradation and retrogradation of sediments which result in the depositional styles of reservoir sandbodies, three main sandstone body types are recognized in the MM sand of study. They are according to decreasing reservoir quality named as follows:
(a) Ribbon to multi-storey channel sandstone bodies. (b) Lobe-shaped sandstone bodies and (c) Sheet-like sandstone bodies. These sandstone bodies are expected to have different reservoir properties since they are characterized by different depositional structure and shape. Ribbon to multi-storey channel sand bodies consist of tidal channels and amalgamated channels. These channels occupy greater part of the MM sand. However, the amalgamated channel has a higher dimension than the tidal channel. Ribbon to multi-storey channel sand body occupy most of the reservoir of study. The reservoir properties of the two channel types are expected to vary. This is not unconnected to the fact that tidal channel which fines upward, consists of very fine grain materials of clay at the upper part and fine to medium grain sandstone beneath. There is heterogeniety as a result of bioturbation and cementation. Interbedded. shale/heterolithics at the upper part will therefore form a baffle to vertical flow. Conversely, the amalgamated channel contains no clay materials and shows a blocky shape in gamma ray log with a good vertical permeability than the tidal channel. Generally, the single to multi-storey channel sandstone forms the best reservoir in the MM sand of study and cut into tidal mouth bar/shoreface sandstone types. The lobe-shaped sandstone bodies are made up of estuarine mouth bar/shoreface and tidal flat sandstones. About 20% of the entire reservoir sand is made up of this sandstone body type. They are less laterally extensive than the sheet-like sandstone but have similar properties. Their porosity ranges from 16% to *24%* and permeability range

(3) Depositional Model Of The MM Sand From the gamma ray log of the reservoir (MM) sand of study; the reservoir could be divided into two sequences based on the mode of deposition. These are the upper and lower part, i.e. the transgressive and regressive sections. Consequently, they are demarcated by an uncored mudstone layer at a depth of about 12373ft in the well. However, the core gamma ray signature shows that the upper part of the lower MM sand and the lower part of the upper MM sand are not cored due to the muddy nature. Therefore, the reservoir model is considered along this line. The upper part which ranges in depth from 12373 to about l2l60ft, consists of the following facies associations, namely from the base; tidal deposit, amalgamated channel, tidal flat, tidal channel, and marine shale. Therefore, the model will be that of transgressive estuarine system. Some of the sedimentary structures associated with the estuarine deposits are reactivation surfaces as a result of the influence of flood and ebb currents (bipolar current) on the sedimentary deposits. Couplets of sand and shale in heterolithic sequence and sporadic trace fossil assemblages with an increase in faunal diversity upward. Furthermore, the lower regressive part of the reservoir sand of study ranges in depth from 12373 to 1248 ft. This lower part which forms a progradational sequence consists of the following facies associations starting from the base of the reservoir sand, offshore marine mud, lower shoreface and upper shoreface. The lower depositional sequence of MM sand are deposits of a prograding wave dominated shallow marine shoreface setting. This interpretation is supported by the abundance of hummocky cross stratification structures, abundance of diverse marine trace fossils, and the upward decrease in diversity and population of these trace fossils.
However, the two channel sandstones in the MM reservoir have different geological properties and should be identified with different geological models. The tidal channel has a transgressive property, that is, it exhibits a fining upward sequence. Also, it has a gradational and erosional upper and lower contact respectively. Furthermore, in gamma ray log, it has a bell shape structure, while in the amalgamated channel of the upper retogradational sequence, it has abrupt upper and lower erosional boundaries respectively, blocky gamma ray log signature and shows little or no separation in neutron-density logs .In summary, the depositional model of the reservoir sand of

study consists of the upper transgressive estuarine deposit sand the lower progradational shallow marine sequence which is being influenced by the presence of bipolar currents involving wave/fluvial processes. A decrease in accommodation space results in a progradation of the facies belt across the shelf thereby giving rise to shelf deposits. Regression is consequently followed by a transgressive phase which resulted in the deposition of the upper part of the reservoir sand or the estuarine deposits. Hence, succession of sediment depositions in the reservoir sand of study involves a transgressive estuarine deposit overlying a progradationalshallow marine shoreface deposits.hummocky stratified sandstone present in the MM is absent in the equivalent sand body unit. This may be as a result of the absence of stormy weather condition which forms part of the tidal channel. Amajor et al, in their study of Viking reservoir sandstone observed the vertical facies sequence of the marine facies from base to the top as prodeltafacies, lower shoreface and upper shoreface, while the upper part of the reservoir constitutes transgressive estuarinedeposits influenced by tidal current. The same depositional sequence is observed in the MM sand and the prodelta facies is characterized by massive
rnudstone. The massive mudstone forms the bottom seal of the sand. Miall et al shows that the prodelta facies is as a result of suspension fallout in a low energy regime. Ichnofacies serve as water depth indicators and are valuable aid to the interpretation of sedimentary environments . Hence, from the different sand body units in the MM sand, distinct trace fossil assemblages are observed. For example, vertical burrows of Ophiomorpha and Skolithos trace fossils occur in the MM sand unit. The animals that formed these trace fossils may have moved up and down in the sediment with the changing water level of the foreshore. There is no biotubation activity seen in themassive mudstone of the bottom seal of the sand. This may be attributed to the unfavorable conditions for organisms to thrive such as absence of light, food and oxygen in the environment

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