Depositional Environment and Reservoir Characterization of The “Bawa” Reservoir Sand, Niger Delta, Nigeria

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ABSTRACT

This research work focuses attention on the Reservoir Characterization of a hydrocarbon bearing Bawa reservoir sand in the well 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 Bawa sand were used for the study. The 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.

Keywords: Reservoir Characterization, Sub-Surface Reservoir, Composite Logs and Amalgamated Sand.

1. INTRODUCTION

Bawa 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 Bawa sand. The research work is intended to unravel the sequence stratigraphy of the Bawa 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). To advance this knowledge, the depositional characteristics of Bawa reservoir sands were studied.

2. AIM AND OBJECTIVES

The objectives of the study are: To provide a detailed Reservoir Characterization of the reservoir Bawa sand ascertain the permeability and porosity values and evaluate the reservoir potential of the reservoir sand and to reconstruct the environment of deposition and provide a depositional model suitable for the reservoir sand.
2.1 Location of the Study Area
The hydrocarbon bearing Bawa sand is located in the central depobelt of the Niger delta.

![Location map of Niger Delta (Study Area)](image)

2.2 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 dominant 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 low stands 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 2: Stratigraphic column showing the three formations of the Niger Delta. (Adapted From: Tuttle et al, 1999)
Figure 3: Major structures and associated traps in the Niger Delta. (Modified from: Doust and Omatsola, 1990; and Stacher, 1995)

Figure 4: Map of the Niger Delta showing province outline (extension from the Calabar flank and Abakaliki trough)
3. METHODOLOGY

There are three methods of study used in the analysis of the reservoir 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 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.

4. RESULTS/INTERPRETATION

4.1 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.

2. 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 an indication of the presence of organic matter.

4.2 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 surface Bioturbation 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 sand 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. It is 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 with overlying 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 lithofacies. In essence, it is an indication of high energy or shallow marine environments.

4.3 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 crossbeds exist. The rippled sandstone is draped by wavy, dark grey mudstone which is asymmetrical with a gentle
slope, an indication of current direction. The lithofacies contains a sporadic bioturbation traces though traces Planolites 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.

4.4 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 stressed estuarine environment. Also, the intensive bioturbation is an indication of lower shore face environment.

![Plate 3: Bioturbated sandstone](image)

4.5 Fossiliferous Sandy heterolitih. This sediment is observed in fine to very fine grained sandy strata. There is abundant 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 lithofacies consists of climbing ripple lamination. Bioturbation activity is moderate to high, though the trace fossils encountered in the 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.
4.6 Reservoir Characterization

The reservoir 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 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 sand obtained. Porosity and permeability values of the 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.

5. DEPOSITIONAL MODEL OF THE BAWA RESERVOIR SAND

From the gamma ray log of the reservoir 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 sand and the lower part of the upper 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 12160ft, 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.

Hence, succession of sediment depositions in the reservoir sand of study involves a transgressive estuarine deposit overlying a progradational shallow marine shoreface deposits. Hummocky stratified sandstone present in the 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 prodelta facies, lower shoreface and upper shoreface, while the upper part of the reservoir constitutes transgressive estuarine deposits influenced by tidal current. The same depositional sequence is observed in the sand and the prodelta facies is characterized by massive mudstone. 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 sand, distinct trace fossil assemblages are observed. For example, vertical burrows of Ophiomorpha and Skolithos trace fossils occur in the 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 the massive 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.

REFERENCES


