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Research Article

DEPOSITIONAL ENVIRONMENT AND RESERVOIR ATTRIBUTES OF JAGO OIL FIELD RESERVOIR SANDS, NIGER DELTA, NIGERIA

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ABSTRACT

The determination of the environments of deposition of reservoir sands within the cored intervals was achieved by careful examination of the log shape, grain size trend, suit of sedimentary structures (physical and biogenic), as contained in each lithofacies, and lithofacies association. Four lithofacies were identified on the cored samples, and the association of the lithofacies aided in reconstructing four sub-environments of deposition. They are; lower shoreface, middle shoreface, tidal flat and tidal channel. The sedimentary core logs of the two cored intervals showing depositional interpretation and key sedimentary structures observed in core samples reflects heterogeneities associated with sedimentary processes; that can have impact on hydrocarbon recovery. Through the analysis of log shapes of reservoir sands not within the cored intervals, point bar and mouth bar were identified. Therefore, the reservoir sands in Jago field are deposited in four aforementioned sub deltaic environments.

INTRODUCTION

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 reservoir sands of "Jago" field, Niger delta were studied.

MATERIALS AND METHODS

Jago field has three oil wells: jago 6, jago 5 and 4, with only jago 6 well cored. Therefore, only the wireline logs and 50m core samples of jago well were acquired for this research to have a general understanding of the reservoir sands in jago field. The wireline logs (gamma and resistivity) of jago 6 well were first of all, qualitatively analyzed. The qualitative interpretation entails visual analysis of log shapes for the identification of reservoir sands, development patterns, hydrocarbon bearing, and prediction of probable environment of deposition and correlating prominent features, such as sharp bases on logs with the corresponding features on the cores. Quantitatively, gamma ray (GR) value greater than 75 API was taken as impermeable zone, while GR value equal to or less than 30 API and less than 75 API was taken as clean sand and permeable zone respectively (Dewan, 1983). The volume of shale (Vsh) (percent mudstone relative to sandstone), of each reservoir units were also calculated.

The core sample which are undisturbed samples that represent subsurface layers penetrated in well drilling, were observed and described based on descriptive parameters, which include rock colour, grain size trend, texture (sorting, and roundness), ichnofossils, lithology, primary and secondary sedimentary structures. Lithology and sedimentary structure were used to name the lithofacies

GEOLOGICAL CORE AND WIRELINE LOG ANALYSIS:

Up to 18 reservoir sand bodies were identified in jago 6 well and they are labelled "A" to "R ". However, only reservoir sand sand "Q" and R" are within the cored intervals, which lie within 2614-2634m and 2719-2739m 3815-3917 depth intervals respectively. The facies identified in the two core intervals are described while the plates of the diagnostic feature of the two intervals are presented in Figure 1-3

CORE DESCRIPTION:

(i) Bioturbatedsand stone - Consist of Fine to medium grained sand stone, moderately to well sorted and greyish brown in colour. Intensely to complete bioturbated, but with some thin undisturbed intervals showing fine inorganic structures (plate 1). Bioturbation indicates low energy conditions, with high oxygen content due to shallow depth, and abundance of nutrient within the substrate and slower rate of deposition. An alternation of bioturbated intervals with intervals showing fine inorganic structures indicates periodic rapid deposition of thick interval which burrowers are unable to penetrate.

Plate 1: Bioturbatedsand stone

(ii) Pebbly Sandstone - Coarse sandstone with gravels and pebbles very poorly sorted. The pebbles are very angular to sub angular. Little sideritic concretions observed at the bottom. 6m thick, and appears massive in most cases with occasional ripple cross lamination. (Plate 2). Bioturbation is zero percent. The coarse grained character and the angularity of the grains indicate short distance of travel and low basinal processes. The very poor sorting and massive nature suggests deposit of episodic flooding, too concentrated to be mobilized by basinal processes.

Plate 2: Pebbly Sandstone

(iii) Heterolithic sandstone - Interbedded sand and shale. 4-25cm thick parallel ripple laminated fine to medium grained sandstone separated by thin layers of shale. There is an occasional hummocky cross stratification. The sand units are well sorted. Vertically, there is a progressive increase in sand/shale ratio, sand grain size and thickness of bed (plate 3). Bioturbation is zero percent. The interbedded sand and shale represents alternation of high and low energy condition. The upward increased in bed thickness, sand shale ratio, and bed thickness indicates progradation. The degree of sorting of sand is due to the strong wave interaction. Deposit associated with suspension settling or sediment fallout to low flow regime, possibly in diurnal or semidiurnal tidal rythmicity. Typical subenvironments of deposition are distal middle shoreface and tidal flat.

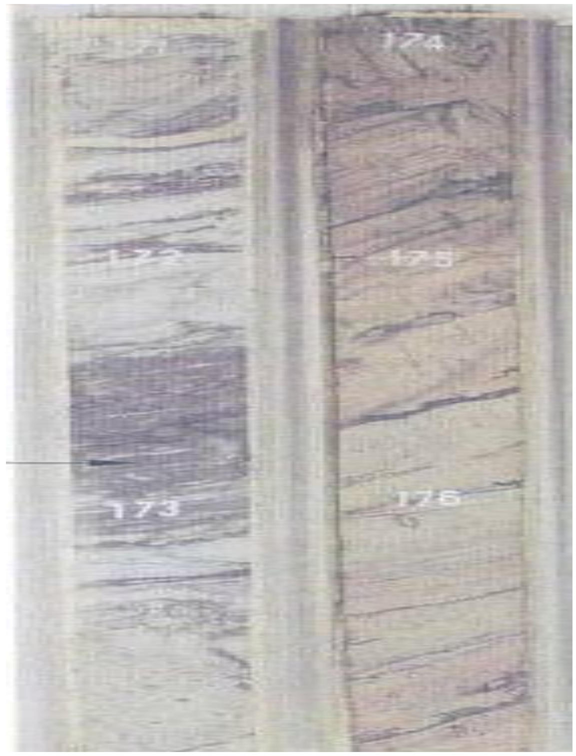

Plate 3: Heterolithic sandstone

LITHOFACIES ASSOCIATION:

(a) Lower shoreface: This is an area were the wave starts to feel bottom (shoaling zone). It is an area of low energy (in comparison to the rest of the seaward system), so it consist of fine grained sand interspersed with thin layers of mud, moderate to intense bioturbation and burrowing. The lithofacies is dominantly muddy, due to the prevalence of low energy condition in lower shoreface. In this study, the vertical facies sequence indicate sedimentary structures which include, flaser bedding, very thin laminations, wavy bedding, hummocky cross stratification and moderate to intense bioturbation structures. All these structures characterized rock deposited in an open marine setting with reduced sedimentation rate and low energy condition. The log curve is characterized on top and bottom by highest gamma ray response with repeated serration, indicating alternations of sand and shale as well as upward coarsening and thickening sequence of lower shoreface. The unit also shows high resistivity due to the occurrence of hydrocarbon on the sandy parts of the heterolithic facies.

(b) Middle shoreface: This is an area overlying the lower shoreface described above. This area is subject to higher wave energy due to wave breaking. Therefore, it is characterized by sand domination, cleaner fine to medium sand and rare bioturbation or unbioturbation. (Reineck 1967). Due to strong wave interaction, the sands are well sorted. Intermittent periods of water quiescence allow suspended fined grained sediment to be deposited as thin layers of shale or mud alternating with thicker sand layers. As a result of landward increase of wave energy, there is an upward coarsening and thickening sequence.

The unit also shows very high resistivity similar to that of the lower shoreface due to the occurrence of hydrocarbon in the sand units of the heterolithic facies.In major depositional settings of Barrier Island System, the seaward side is made up of the lower shoreface, middle shoreface, upper shoreface, foreshore and back shore. In this study, it is observed that the progradation of middle shoreface to foreshore/backshore was interrupted as indicated by an overlying erosive base or minor sequence boundary. The proximal part of the middle shoreface was possibly eroded. This is based on the fact that a complete sequence of middle shoreface rocks is also characterized by multi directional cross bedding due to changing wave direction which changes direction of the long shore current and also, trough which are scoured by long shore current (Readings, 1981). The absence of these structures prove that heterolithic sandstone lithofacies is most possibly that of distal part of middle shoreface.

(c) Tidal Channel Lithofacies: The stacking of shale, laminated sandstone and small scale cross bedded/horizontal bedded sandstone lithofacies is interpreted as tidal channel lithofacies association. As shown in the sedimentary core log, the facies sequence is made up of sand grains that grade from fine to very fine. The alternations of millimeter scaled cross beds with millimeter scaled flat beds are attributed to pulsating flow tidal current in tidal channel . Tidal channel deposit is normally characterized by herringbone cross stratification. However, it only develops in regions where the ebb and flood flow pathway overlap. When the region is made up of multiple pathways with some channels experiencing only one dominant flow, the ebb and flood tidal current commonly follow different pathways, with some channels experiencing only one dominant flow. The non-identification of herringbone crossstratification in tidal channel lithofacies association in this study can be attributed to this phenomenon. The log shape of this unit shows a general fining upward sequence with a sharp basal contact and large-scale serrations from edge to the top. it is assumed they are all made up of the same lithofacies association. Therefore, they are all interpreted as tidal channels.

DISCUSSION

A sedimentological study/analysis of cored samples was integrated with qualitative analysis of wire line logs of Jago 6 well to understand the depositional environments characteristics of the reservoir sands in Jago field. Analysis of the grain size, lithology, physical primary sedimentary structures, biogenic structures and gamma ray log shapes were integrated to recognize the following sub environments of deposition.

Lower and Middle Shoreface: Shoreface is defined as the interval between the mean sea-level and the mean fair-weather wave base (FWWB, Walker & Plint 1992). FWWB is the depth to which the typical daily waves affect the sea bottom. (Howell et al., 2008). According to Oomkeens (1974), "in regressive sequences, deeper-water sediments are successfully overlain by sediments deposited in progressively shallower water. In the

Niger Delta, the basal member of the regressive marine sequence consists generally of sandy clays. The topmost part of the regressive sequence is composed of predominantly horizontally bedded sands that showed an upward increase in grain size." The unit described as lower and middle shoreface rocks in this study is similar to the regressive sediment described above. However, the normal sequence of prograding clastic shoreline which grades from lower shoreface to uppershoreface made up of barrier bars and beaches was interrupted. The interruption is represented by an erosive boundary overlying the middle shoreface rocks. It shows that a barrier bar was eroded by the distributary channel described below. The characteristics of the lower shoreface are also in line with that documented by Davies et al., (1988). However, lower shoreface was divided into proximal lower shoreface and distal lower shoreface based on their strata thickness, log response and reservoir quality. Proximal lower shoreface was identified with sandstone dominated heterolithic facies, while distal lower shoreface was identified with mud dominated heterolithic facies. His proximal lower shoreface is slightly similar to the distal middle shoreface identified in this study. Also, the lithofacies association of these sub-environments is similar to the facies of shallow marine siliciclastic deposit described by Reading (1981). He described shoreline siliciclastic deposit as made up of sand facies, sand dominated heterolithic facies, and mud dominated heterolithic facies and mud facies. This corresponds to a gradation from foreshore to offshore facies. In addition, the characteristics of the lower shoreface identified in this study are also in-line with those identified in the Niger Delta by Weber (1971). He stated that there is a gradual change of sedimentary characteristics from bioturbated clays with occasional silt and sand lenses (transition zone), which passes upwards into interbedded muds, silts and sand (lower/distal middle shoreface). Towards the top of the sequence, there is either a gradational passage into well sorted parallel-laminated sands of beach face, or the sequence is cut by a distributary channel. The middle shoreface facies can be taken as proximal fluviomarine or barrier foot and lower shoreface as distal fluviomarine of Weber (1971). In this light, the very high gamma ray value of this sand unit could be attributed to high clay content and high percentage silt size zircon.

Tidal flat and tidal channeL: Readings (1981) stated that tidal flat comprises almost featureless plains dissected by networks of tidal channels and creeks. Tidal flat tends to produce a fining upward sequence, which reflects transition from low tide level sand flat, upward into high tide level mudflat and eventually into supratidal flats. In other words, a reflection of a decreasing wave action in the progression from subtidal to intertidal to supratidal parts of the tidal flat; indicates a regressive process. This sequence may be cut at any level and in some case completely replaced by erosive tidal channel sequences. However, Thompson (1975) reported that the tidal flats in the Gulf of California are dominated by fine grained sediments and the facies changes from subtidal to supratidal, and therefore occur within a silt clay sequence with no fining upward trend. The facies sequence of tidal flat in this study which grades from bioturbated sand to sand stone with mud layers is a fining upward sequence.

The lithofacies associations of tidal channel identified in this study is similar to that described above, except the absence of coarse intra formational lag. However, all the sedimentary structures encountered are also of centimeter to decimeter scale. Upward increase of burrows (planolite and Ophiomorpha burrow) and clay content were also observed.

Using wire line logs and core analysis, a total of five tidal channel deposits were identified based on Schlumberger (1985) electrofacies classification scheme. The numerousity of tidal channel deposits in jago 6 well supports the findings of Allen, (1965), that in the Niger Delta areas, interdistributary areas are dominated by mangrove swamp (vegetated inter-tidal flats) dissected by tidal distributary channels and a complex pattern of meandering tidal creeks,each served by numerous small scale dentritic drainage systems

RESERVOIR QUALITY:

The quality of reservoirs in an oil field is influenced by the distribution of facies and the external geometry of the reservoirs. In a depositional system, facies, facies assemblage distribution and spatial portioning within sandstone result to reservoir heterogeneity, which is the lateral and vertical change in rock properties. Few traps contain reservoir that are uniform in thickness, porosity, permeability; most are heterogeneous (Selley, 1998). Thus, Galloway and Hobbday (1996) identified five levels or sales of reservoir heterogeneity: gigascopic, megascopic, macroscopic, mesoscopic, and microscopic. Gigascopic heterogeneity is shown at the scale of depositional systems, while megascopic heterogeneity deals with the geometry of permeable and impermeable units-a scale applied in identifying reservoir units and for correlation between outcrops and borehole, and for depositional interpretation (Keyu et al., 2004). Macroscopic heterogeneity is at the facies scale and help to understand depositional processes.

Mesoscopic heterogeneity occurs at the scale of lithofacies and stratification; while microscopic heterogeneity is expressed at the scale of individual grains and pores. In this study, heterogeneities of reservoirs in Jago field were analyzed down to mesoscopic level, taking into consideration of the limitation of one dimensional data of just one oil well. On a megascopic level, heterogeneity of permeability is reflected by gamma ray differentiating sand bodies (permeable zones) and shale (impermeable zones). Also, the volume of shale of each sand unit indicates that most of Niger delta Agbada paralic sands form good reservoir on a megascopic scale. On macroscopic-mesoscopic scale, shale and mud occurring as isolated muddy and silty beds, flaser bedding, mud drapes and overbank deposits are taken as baffles or permeability barriers and where they are continuous can form several flow units within the sand bodies. The analysis of lithofacies and stratification aided the separation of tidal flats from tidal channel and middle shoreface from lower shoreface. Galloway and Hobbday, (1996) documented the vertical connectivity and lateral continuity of various reservoir sequence; which was used to predict the areal quality of reservoirs in Jago field. Tidal flat reservoirs are characterized by moderate lateral continuity and poor vertical continuity as a result of mud layers that creates vertical permeability barrier. On a lithofacies and stratification scale, tidal flat is taken as poor reservoir as a result of finer-grained sediment, lots of disruptive bioturbation and burrow lining or filling with clay. Similarly, tidal channel reservoir also formed moderate lateral continuity but with also moderate vertical connectivity. The vertical connectivity is moderate as a results silty clay breaks and mud beds that punctuate the reservoir.

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