The Lamja sandstone in Northeast Nigeria: Sedimentology and reservoir quality

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The Lamja Sandstone conformably overlies the Numanha Shale. The exposures of the formation occur on the eastern and southern fringes of the Tertiary Lunguda Basalt Plateau. The Lamja Sandstone consists of shale, coal, siltstone, sandstone, sandy limestone and carbonaceous sandstone. The dominant sedimentary structures are parallel lamination, cross bedding, cross lamination, cross stratification, planar bedding and bedding planes. Petrographic studies show that the sandstone is poorly-moderately sorted, very fine-fine grained and sub-angular-sub-rounded. Granulometric data show a graphic mean size of 2.82ø (fine grained sandstone), mean standard deviation of 1.62 (poorly sorted) while the skewness values are positively fine skewed, and kurtosis; showing an average value of 0.860 (mesokurtic). Bivariate plots standard deviation versus skewness, standard deviation versus mean; and standard deviation versus first percentile for sample studied cluster within the river environment. The cumulative probability curves plotted, showed that most of the samples are characteristics of fluvial.

Keywords: Lamja sandstone, sedimentology, depositional environment, reservoir quality, poorly sorted.

INTRODUCTION

The Lamja Sandstone lies in the north-eastern part of Nigeria (Fig. 1). It occupies part of sheet 47 (Lau) of Geological Survey of Nigeria (GSN) map (1:250,000). Exposures of the formation occur on the eastern and southern fringes of the Tertiary Lunguda Basalt Plateau. A depositional environment is usually characterized by a particular geomorphic setting in a particular set of physical, chemical and biological processes to generate a certain kind of sedimentary deposit (Boggs, 1995). Ancient depositional environments can be inferred from integration and interpretation of its gross lithology, facies, facies sequences, sedimentary structures, trace element, fossils (trace fossils), petrographic and granulometric data (Boggs, 1995, Uchebo, 2010).

Lamja Sandstone of the Yola Basin, of the Upper Benue Trough according to Odebode (1987) is Coniacian - Santonian and was named by Carter et al. (1963) (Fig. 1) The formation conformably overlies the Numanha Shale and terminates the sedimentary succession in the Yola arm. Those who studied the formation include Cratchley and Jones (1965), Petters (1978a), Whiteman (1982), Allix (1983), Odebode (1987) and Opeloye (2002). The Lamja Sandstone is one of the least geologically studied formations in Nigeria. Earlier studies by (Barber et al; 1954, Offodile, 1980; Allix, 1983; Enu, 1986; Enu et al., 1987; Mamman, 1998; Obaje et al., 1999; and Opeloye,
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The study area

Figure 1. Geological map of Nigeria showing the study location in the Upper Benue Trough (modified from Obaje et al., 2011).

Figure 2. Geological map of the Benue trough (inset: map of Africa and Nigeria indicating separation of Africa from South America, geological subdivisions of the Benue trough (modified from Uzoegbu et al., 2013b).

2002; Uchebo, 2010) among others emphasized some aspects of sedimentology, stratigraphy and geochemistry, as well as palynological dating of Lamja Sandstone. However, the detail sedimentologic studies of the Lamja Sandstone of the Yola Basin have not been carried out. The purpose of this paper is therefore an attempt to describe the sedimentological characteristics, depositional environment and petrography of the Lamja Sandstone and highlight its reservoir quality.

REGIONAL GEOLOGIC SETTING

The Benue Trough of Nigeria is an intercontinental basin in central West Africa that extends NNE to SSW for about 800 km in length and 150 km in width. The southern limit is the northern boundary of the Niger Delta while the northern limit is the southern boundary of the Chad Basin (Borno Basin) separated from the Benue Trough by the "Dumbuluwa - Bage high" which does not occur across
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The Benue Trough is geographically subdivided into lower, middle and upper parts (Fig. 2). The origin and tectonic history of the Benue Trough is associated with the separation of Africa and South America (break up of Gondwanaland) during the early Cretaceous time (Benkhelil, 1989). This break up was followed by the drifting apart of these continents, the opening of the south Atlantic and the growth of the Mid Atlantic ridge (Benkhelil, 1989).

The upper Benue Trough (Fig. 2) is Y shape made of the three arms, the north-south trending Gongola Arm, the east-west trending Yola Arm and the Lau-Lamurde Arm (Benkhelil 1989, Guiraud 1990b, Dike 2002). Some authors however recognize two arms, the Gongola Basin and the Yola Basin (Obaje et al., 2004). The stratigraphic subdivision of the upper Benue is shown in Fig. 3.

In the Yola Basin, the Bima Sandstone is the oldest sedimentary formation. Other formations are the Dukul Formation, the Jessu, the Sekuliye, the Numanha and the Lamja sandstone are uncoformably overlain by the Tertiary Basalts of the Lunguda Plateau. Gombe Sandstone and the Kern Kerri formation were not deposited (Fig. 3).

MATERIALS AND METHODS

Seven samples were selected for sieve analysis. The samples were disaggregated into individual grains by the use of ceramic pestle and mortar, and about 126.0gm of each sample were then soaked in hydrogen peroxide for 12 hour. Wet sieving was carried out using 63-μm...
The grains are very fine to fine grained, white or brown, silty sandstone. The carbonaceous sandstone sections are exposed in the village of Lamza Sama, Kola, Lidiye and Jou. Lamza is located 1.5km to the SW of Lamza village. The section consists of over 5.4 meter of sediments. The lithofacies contain series of brownish silty sandstone at its base, overlain by grey shale to bituminous coal to grey shale then capped by whitish-grey silty sandstone. The fine grained silty sandstone units exhibit parallel laminations (Fig.4a). Kola section is located 2km to west of Kola village. This section consists of about 50m of massive dark grey to black fine grained carbonaceous sandstone (Fig. 4b). Lidiye is located 300m to the NW of Lediye village. The section consists of a coarsening upward unit about 1.5m (Fig. 5a). Jou section is located 105m SE of Jou village. The sediment thickness is about 3.8m with bituminous coal at the base overlain by shale and capped by white-brownish silty sandstone with parallel lamination. Grains are not only fine but also moderate to poorly sorted (Fig. 5b). Boundary between beds is sharp.

The graphic mean size for various samples within the study area ranges from 2.50 to 3.11 (fine grained sands) (Table 1). All values indicated poorly sorted with mean value of 1.62. Populations with a tail of excess coarse particles are negatively skewed or descriptive.

**Facies Analyses**

Four categories of facies were recognized in Lamja Sandstone. These include sandstone, carbonate, coal and shale facies. Sandstone facies is parallel laminated structure occurred in most of the sections. The grains are very fine to fine grained, white or brown, silty sandstone. The carbonaceous sandstone...
is apparently structureless carbonaceous sandstone typically occurs at Kola section. The sandstone is fine grained, highly indurated and massive in nature (Fig. 4a). In coal facies, coal seams are present in Lamza Sama and Jou sections. They appear to be bituminous clarain coal. Individual coal seams exhibited abrupt contact. The coal samples generally have low moisture contents (below 10%) but with a considerable mineral matter more than 15-75 %ash content) (Opeloye, 2002). In shale facies, shale deposits are found at Lamza Sama and Jou sections and are grey to black in colour with transitional contact. The histogram plotted on samples display bi-modal characteristics which may suggest of more than one source to Lamja Sandstone (Figs. 6-7).

Eight samples were selected and petrographically studied under the microscope. The sandstone samples consist mainly of quartz and feldspar as framework components with clay matrix and cements. In the studied samples quartz comprises an average of 65% of the components minerals. It was observed that some of the quartz grains exhibited straight extinction while a few of them showed
undulating extinction. Both monocrystalline quartz and polycrystalline quartz occur but monocrystalline quartz dominates. Feldspars and plagioclase were identified. Rock fragments constituted 3-5% of the sandstones. Quartz overgrowths were not identified. Coal seams of about 0.34 to 1.84 m were seen in Jou, Hemi and Lediye.

DISCUSSIONS

Facies

Sedimentary facies is a mass of rock which can be defined and distinguished from others by its geometry, lithology, sedimentary structures, palaeocurrent pattern and fossils (Selley, 1970, 1988, 1993; Ladipo et al., 1992; Ojo and Akande, 2009; Vakarelov and Bhattacharya, 2009; Omali et al., 2011; Obaje et al., 2011; Uzoegbu et al., 2013a). A sedimentary facies is a product of a depositional environment. Facies sequences is thought as a group of facies that occurs together and genetically or environmentally related.

**Facies and Sequences of Lamza Sama section**

Brownish silty sandstone at the base to grey shale to bituminous coal to grey shale and capped by whitish grey silty sandstone constituted the facies of this section. The grains are fine, exhibits parallel lamination structure and the petrographic studies indicated that the grains are moderately sorted and also they are sub-rounded grains. Deposition of coal seams and lack of glauconite may suggest none fully marine environment (Selley, 1970, Odebode, 1987). The Probability plot of the sample tends to indicate only one sand population curve. This may suggest deposition in a fluvial setting (Fig.8)
In the Lidiye section brown-yellowish silty sandstone, parallel lamination structures. Both granulometric and petrographic studies revealed that the samples are poorly sorted. The probability plots for samples of this section also showed two sand population curves. Dike (1972) indicated that two sand population curves can occur also in tidal setting; hence it may be associated with a unidirectional current. The results may suggest deposition in deltaic setting (Fig. 9). The Jou section is characterized by massive brown-whitish silty sandstone.
with parallel lamination. The sandy limestone at the base may reflect marine incursion however the probability plots for samples of this section show two sand population curves, in addition to poorly sorted grains from petrographic and granulometric studies of the samples, it may suggest deposition in deltaic to shallow environments. (Fig. 9).

Environmental Synthesis

The Lamja Formation is characterized by fine-very fine laminated silty sandstone which display varying colour characteristics ranging from light brown to dark brown, whitish and grey colour, bituminous coal which falls within clarain type which under vitrinite group (Opeloye, 2002) and silty shale which is light dark grey in colour. In the study area parallel laminated structure occurred in most sections. Laminae are produced by less severe or short-lived fluctuations in sedimentation conditions than those that generate beds (Boggs, 1995). Steady flow of current may produce parallel lamination. They form in variety of sedimentary environments. Burrowing and feed organisms destroy this lamination. Preservation of this is either reducing/oxic environment. The sandstone exhibits both gradual and sharp termination and reflect distributary channel deposits within fluvial dominated delta.

The presence of coal really rules out the possibility of fully marine environment (Dike, 2005). Lack of Dinoflagelletes and accritachs also rule out a fully marine environment (Odebode, 1987; Ojo, 2009) while carbonaceous sandstone reflects deposition either in interdistributary bay or crevasse splays deposits of deltaic environment where vegetation is not only much but has undergone quick burial which gave rise to high organic matter.

However, the occurrence of thin limestone layers in some outcrops coupled with the recovery of Pycnodonte vesicularis specimen from it indicate marine incursions into Lamja basin during the Sandstone’s deposition (Odebode, 1987). Chamley et al. (1979) used the proportions of the different clay minerals (chlorite, montmorillonite, illite, kaolinite and interstratified species) in the sediments to trace the upper Benue basins tectonic
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Univariate grain size parameters cannot conclusively suggest a depositional environment but can give a clue to some significant processes occurring within an environment of deposition. Boggs (1995) indicated that sorting depends on sediment source, grain size and depositional regime. Sorting of Lamja Sandstone is poorly sorted but positively skewed indicating a predominance of finer grain materials. River sands are generally positively skewed are in consonance with Friedman's (1961, 1967) data for fluvial sands. The bivariate plots of Friedman (1961, 1967) for skewed versus standard deviation, Moiola and Weiser (1968) for skewness versus standard deviation and mean versus standard deviation, Friedman's (1979) plots for mean versus first percentile and standard deviation versus first percentile and Friedman's (1967, 1978) plots for standard deviation versus skewness and standard deviation versus mean all suggested fluvial in origin for Lamja Sandstone. Probability curve plots based on Visher, (1969) and Dike (1972) indicated most of the samples to have two sand populations (saltation and suspension) (sample 4A, 6B, 7B and 8C) while sample 1A, 2B and 5C have only single (suspension) of sand population probability.

The Lamja Sandstone is here interpreted as partly continental in origin and partly marine as a result of regressing sea (Odebode, 1987). The marine regression was probably caused by combination of tectonism and withdrawal of the Turonian Sea during the Coniacian-Santonian regression when the Lamja Sandstone was deposited. Odebode (1987) also indicated that as the sea withdrew southeastward during the Late Coniacian to

**Figure 9.** Paleoenvironment of Lamja Sandstone sequences at Lidiye (A) and Jou (B).
Early Santonian times, it deposited part of the formation in the continental to swampy/marshy northeastern part of the basin. This is partly wholly in line with the paleogeographic models of the Benue Basin of Adeleye (1975), Kogbe et al. (1978), Kogbe (1981), Petters (1978a), and Reyment and Tait (1983), among others distinguished workers. The bivariate plots of standard deviation versus skewness are based on the work of Friedman (1961, 1967, and 1979) and Moiola and Wesier (1968). Using...
the distinctions of Friedman (1961), the plot showed that the samples are distributed within the river field (Fig. 8). Friedman (1967) showed distribution of sand parameters between river and beach environment while most of these samples were deposited within fluvial environment (Fig. 9). The plots based on Friedman (1979) showed that all the samples plotted within the river field environment, the plots based on Moiola and Weiser (1968) showed that the studied samples fell into the river field environment.

The standard plot of mean versus first percentile was based on the work of Friedman (1978) which was used in distinguishing inland dune sand from river sand. The plots for the samples tend to show that all the samples fell into the river sand environment. Friedman (1979) plotted a graph of standard deviation versus first percentile; the plot indicates that all the samples fell into the river field sand.

The bivariate plots of standard deviation versus mean size is based on the work of Moiola and Weiser (1968). This was used in distinguishing dune sand from river sand. All the studied samples fell into river field. The plots of standard deviation versus mean size based on Friedman (1979) also showed that all sands samples fell into river environment.

Visher (1969), Glister and Nelson (1974) and Sagoe and Visher (1977) have all suggested that depositional environment can be interpreted on the basis of the shapes of grain size cumulative curves plotted on log probability scale. Cumulative curves plotted in this way commonly display two, three or four straight line segments and rarely a single straight line. Each segment of the curve is interpreted to represent different subpopulations of grains that were transported simultaneously but by different transport modes, that is by suspension, saltation, and bed load transport (traction). Sediments from different environments (dune, fluvial, beach, tidal, nearshore, turbidite) can putatively be differentiated on the basis of the general shapes of curves, the slope of the curve segments and position of the truncation points (break in slope) between the straight line segments (e.g. Visher, 1969). Although success using these various techniques has been reported by some investigators, nevertheless according to Visher's (1969) characterization: two sand populations are characteristic of fluvial settings (Fig. 10), three sand populations are characteristic of wave zone bars( Fig. 11) and four sand populations are characteristic of beach settings (Fig. 12).

However, Dike (1972) recorded two sand populations (Fig. 10) in tidal channels/ estuary sands and along tidal current transport paths in the shelf where sand ribbons and sand waves are dominant, four sand populations in beaches with foreshore beach laminations (Fig. 12) and

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**Fig. 12: Probability curve shape of beach environment.**
three sand populations curves (Fig. 11) in wave zone/tide formed sand bars (e.g. tidal delta, subtidal delta, nearshore and bars and shoals associated with tidal embayment. Cumulative probability distribution curves of analyzed samples tend to show two straight line segments. Samples displaying two segment probability curves are 4A, 6B, 7B, and 8C. The samples characterized by one segment probability curves are 1A, 2B and 5C. They are characterized by poorly sorted suspension population. Visher (1967, 1972) reported that sands mostly deposited by strong unidirectional current show saltation and suspension population to be predominant, unless the sand sample is particularly coarse. The sample of the cumulative probability curves plotted for the samples studied are characteristic of fluvial log-probability plots and appears to be diagnostic for fluvial environment. A single segment curve of sample 1A, 2B and 5C may suggest the dominance of the low energy flow or weak waves.

**Petroleum System, Potential and Reservoir Quality in the Region**

The potential source rocks of this possible petroleum system in the Gongola Basin are shales and limestones of the Pindiga and Fika Formations and perhaps the coals of the Gombe Formation, and correlative Dukul, Jessu, Sekuiye, Numanha and Lamja Formations in the Yola Basin (Fig. 3).

**CONCLUSIONS**

The Lamja Sandstone is one of the least geologically documented formations in Nigeria. Unlike the Gongola Basin of Upper Benue Trough, the Lamja Sandstone of Yola Basin of Upper Benue Trough has few outcrops and thin geological sections. Nevertheless, the limited outcrops shed a light on the depositional environmental characteristics of the Lamja Sandstone. Lamja Sandstone consists of coal, silty sandstone, carbonaceous sandstone and shale. These lithologic units display varying colour characteristics. The colour differences reflect type of cementing material binding the (Pettijohn, 1975). Petrographic studies revealed that the samples are poorly to moderately sorted. The sandstone samples are not only texturally and mineralogically immature but are fine to very fine grained. Granulometric analysis also indicates that the sediments are poorly sorted, fine grained and positively skewed. From the result of the analysis, a possible fully marine depositional environment is ruled out while the results reflect deposition in swamps, distributary channels to interdistributary bay subenvironments. The absence of glauconite and phosphorite in the sediments likely suggests deposition in deltaic environments to shallow marine on account of limestone at the base of the sequence. The poor-moderately sorted sandstone units of the fluvial influenced facies of the Lamja Sandstone may not provide a good reservoir quality.

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