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Lithological and Depositional Environmental Assay of HMU-Well Reservoir Sands, Offshore, Niger Delta Basin, Nigeria

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INFORMATION

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ABSTRACT

One hundred and seventy-seven ditch cutting samples were collected from HMU-Well, Niger Delta Basin, at intervals of 5715 to 8695ft which marks the total depth of the Well. The samples were subjected to sedimentological and heavy mineral analyses. Ten (10) depths of interest were selected for sedimentological analyses. The heavy minerals present include zircon, hornblende and glauconite. Pickett cross plots were integrated in the reservoir quality and depositional environment of sand bodies of the HMU-Well, Offshore, Niger Delta. Evaluated parameters include; storage properties (porosity and saturation) flow property (permeability) as well as reservoir heterogeneities. Results show that the sands are texturally and compositionally mature as a result of high quartz arenite present. In general, quartz composition ranged from 85.25% to 95.48% conforming to the sandstone maturity, sample nine (9) showed the highest quartz arenite value with 95.48%, sample ten (10) with 93.25% and sample three (3) with 93.10%. The porosity is good to very good with porosity value of 9% to 11%. The sandstone bodies are sourced from mainly felsic igneous rocks and from low to high grade metamorphic rocks. The depositional system is fluvial while, the depositional environment is coastal plain. The reservoir quality of HMU-Well, is good and will yield optimal output on production.

1. Introduction

The Niger Delta oil fields are characterized by structural and stratigraphic and depositional heterogeneities that impact hydrocarbon production (Short and Stauble, 1967; Weber, 1971; Doust and Omatsola, 1990). Some of the oil fields are matured and on the verge of being abandoned due to low economic viability. The depositional study is the analysis of the depressed environment where sediments have been deposited. The geographical location, physical and chemical parameters, as well as the parent rock in that zone would determine the sediment type that is deposited in such environment. Identification of depositional environment is based on the lithology of the area, sedimentary structures and fossils present. Depositional environment is categorized into continental, marginal-marine and marine environment (Mahesha and Balasubramanian, 2013; Selley, 2001).

The continental environment includes fluvial, alluvial, river, aeolian, lacustrine and glacial environment (Mahesha and Balasubramanian, 2013). The marginal-marine environment includes beach, barrier-island, lagoon, deltaic, estuary and tidal-flat environments. The marine environment includes shallow marine and deep marine environments (Mahesha and Balasubramanian, 2013). However, previous geological investigations have paid insufficient attention to the lithofacies characterization.

Modern and ancient sedimentary environments can be identified from core samples, ditch cuttings and outcrops using distinct sedimentary structures (Slatt, 2006). Cores of sedimentary rocks are important and diagnostic in environmental reconstruction because it contains rock in situ parameters. Environments of deposition of Niger Delta formations have been studied using cores, ditch-cuttings (Amajor and Agbaire, 1989; Reijers, 2011). This study was undertaken to identify and describe the lithofacies, sedimentary processes and paleo-depositional environment. The depositional environment study enables sound prediction and description of reservoir quality including its distribution (Mode et al, 2016). Therefore, the aim of this study is to characterize the identified reservoirs and to determine the paleo-depositional environment of HMU-well. The Niger Delta Basin has spectacularly maintained a thick sedimentary apron and relevant petroleum geological features favorable for petroleum accumulation from the onshore through the continental shelf and to the deep-water terrains. The onshore and continental shelf Niger Delta is being explored for more than half a century now. However, exploration activities are gradually being shifted to the deep offshore to unveil its hydrocarbon potential. The deep-sea channel sandstone bodies are the main exploration target in this section of the Niger Delta (Whiteman, 1982).

A lot of information about the sediments and sedimentary processes is contained in the basin. Sediments in different paleo-environments display characteristic log motifs. Reservoir quality and depositional environment of sand bodies can be evaluated using data from ditch cuttings obtained from HMU-well, offshore western Niger Delta. The paleo-depositional environments in the field will be inferred from the lithologic model of the penetrated sedimentary succession within the HMU-well.

2. Location and Geological Setting

The well under study is pseudo-named HMU-Well, Niger Delta Basin, in accordance with the Company's confidentiality agreement. The field is located within the offshore compressional features of the Niger Delta Basin, south-south, Nigeria (Fig. 1). The field belongs to an active oil producing company in Nigeria. It covers an area of about 51.137 km^2 and it is within longitude 9.0° E to 9.5° E and Latitude 5.0° N to 6.2° N. The Nigerian pericratonic basin was formed by rift faulting of the Pre-Cambrian (Doust and Omatsola, 1989).

The outlines of the Niger Delta are controlled by deep-seated faults along the Benin and Calabar hinge lines (Momta and Odigi, 2016). At least three major sedimentary cycles have been deposited in the basin since early Cretaceous time (Reijers, 2011). The delta started growing during the second cycle between Campanian and Paleocene transgressions (Momta and Odigi, 2016). The third sedimentary cycle that occurred during the Paleocene accounted for the formation of the Niger Delta. The deltaic sequence consists essentially of clayey marine sediments overlain by paralic sediments, i.e., mixed continental, brackish water and marine deposits, which are covered by continental sands and gravels (Momta and Odigi, 2016).

Generally, sediments belonging to the Benin Formation represent the sub-aerially exposed part of the delta. The main prospective interval, the Agbada Formation is a regressive offlap succession that formed under shallow-marine conditions in active Depobelts of the Delta where subsidence rates were 500-1000 m/Ma (Reijers, 2011). Such depositional rates occasionally resulted in gravity-induced mass transport over the over pressured Akata shales and as a result triggered large scale flows of the over pressured shales that became squeezed out, such as also reported from the offshore by (Owoyemi and Willis, 2006; Magbagbeoloa and Willis, 2007). These units form the backbone for the analysis of the cyclicity and the genetic sequences (Reijers, 2011).

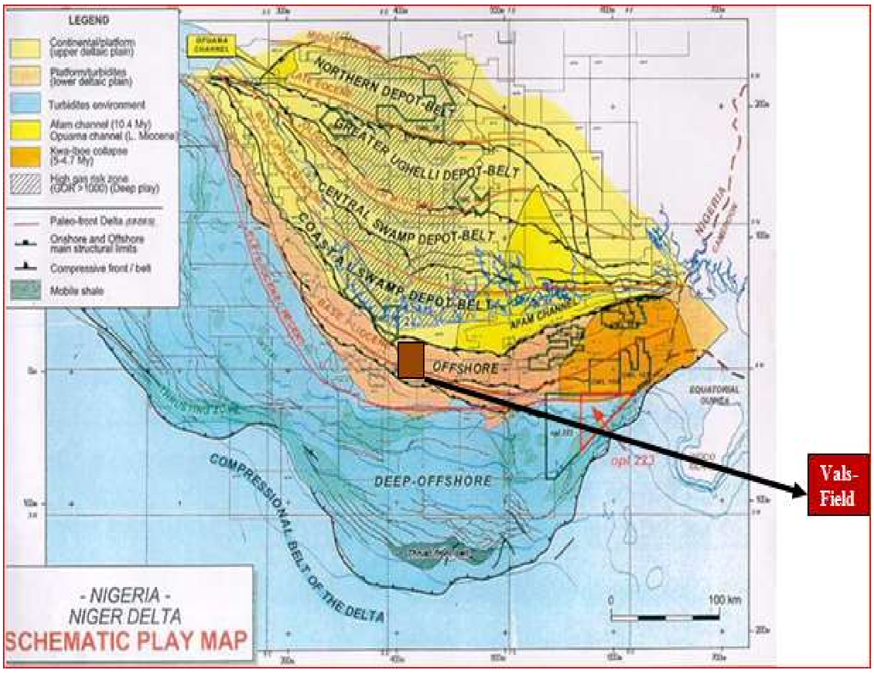


Fig. 1. Map depicting the study area (HMU-Well), after Nwozor et al. (2013)

3. Materials and Methods

The data and interpretations presented in this study were based on detailed examination of one hundred and seventy-seven (177) ditch cuttings samples from HMU-Well, Offshore, Niger Delta Basin which represent the sedimentary succession of depth range within the interval of 5715-5730 ft to 8680-8695 ft was provided by the Nigerian Petroleum Development Company (NPDC), Benin City, Edo State.

Sedimentary description was undertaken from bottom to top, and the various sedimentological parameters such as lithology, grain size, sedimentary structures, texture, nature of contacts and sorting were deduced in an attempt to reconstruct the paleo-environments, hydrodynamics and characterization of the lithofacies encountered and construction of a sedimentological model for the well. Standard visual charts of grain size and sorting determination of Tucker (1996) was also utilized in this study.

4. Results and Discussion

4.1. Grain Size Analysis

Ten sample points (8090, 8103, 8133, 8208, 8326, 8415, 8369, 8415, 8444 and 8484 ft) were subjected to grain size analyses and the result are shown in Table 1. The data obtained were plotted on a Ternary diagram (Fig. 2) according to the classification system of Pettijohn et al. (1987). Most of the samples fell within the quartz arenite region and a few on the sub feldspathic arenite region. This is an indication of a high quartz composition and minimal feldspar content of the samples. The high quartz arenite content is also an indication that the samples are texturally and compositionally mature (Table 1). The highest quartz arenite content was observed in sample 9 with 95.48% quartz content. This is followed by sample 10 with 93.25% quartz content and sample 3 with 93.10% quartz content.

In general, the quartz composition ranges from 85.23-95.48%, thereby conforming to the maturity (Table 1) of the sandstones that make up the reservoir sand of HMU-well.

Table 1. Summary of results of grain size, mineral composition, and chemical index of maturity

Sample depth (ft)	Average grain size (mm)	Quartz composition	Feldspar composition	Chemical index of maturity
2466	0.02	85.23	8.49	6
2470	0.013	87.04	6.1	7
2479	0.2	93.1	6.72	14
2502	0.018	91.25	13.21	10
2524	0.02	88.69	10.04	8
2538	0.015	91.02	13.88	10
2551	0.013	88.06	8.87	7
2565	0.25	85.33	9.48	6
2574	0.015	95.25	10.33	21
2586	0.02	93.25	15.06	14

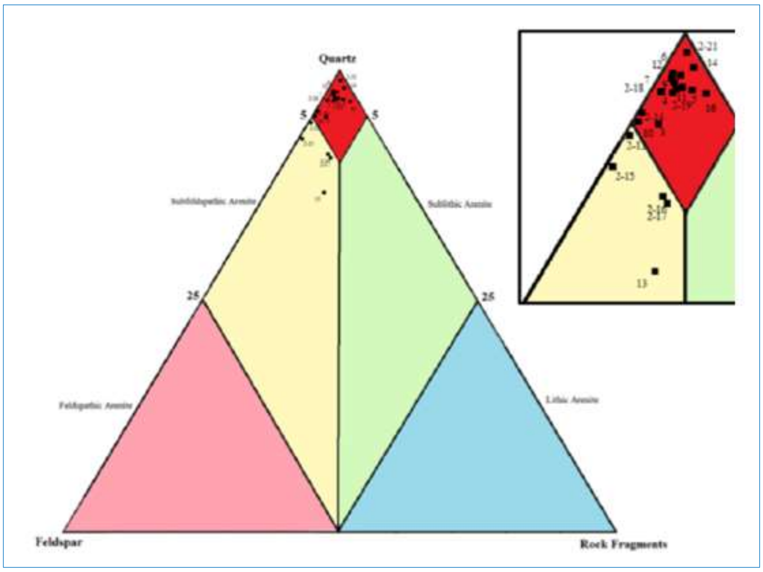


Fig. 2. Classification of samples following Pettijohn et.al. (1987)

4.2. Textural Properties of the Reservoir Sand Bodies

There is no particular order in the distribution of the grain sizes in the sand bodies of HMU-well with depth as it fluctuates within the ten samples. The grains are medium to fine-grained. There is also no record of coarse-grained sandstone in the sampled depths, indicating that the sediments must have been transported from the source and were not studied in-situ.

4.*3. Grain Sorting of the Reservoir Sand Bodies*

Except for depths 2466 m, 2524 m and 2565 m, which are poorly sorted, other samples were moderately to well-sorted (Table 2). This is the result of the volume of spaces between the grains higher or finer grains. It also shows that the well sorted the grains, the better the porosity and the degree of uniformity of the grains size.

4.4. Provenance

Heavy minerals are characteristic minerals found in metamorphic and igneous rock, some are also diagnostic of sedimentary rock; these minerals are usually resistant to chemical weathering and occur in accessory order in sedimentary rocks. They are usually less than 1% of the rock composition. These heavy minerals have specific gravity greater than 2.65 which is the specific gravity of bromoform. For the sandstone analyzed, the major heavy minerals are zircon, hornblende and tourmaline (Table 3). From the table, it is shown that zircon is sourced mainly from felsic igneous rocks; hornblende is sourced from felsic igneous rocks and high-grade metamorphic rocks. On the other hand, tourmaline is sourced from high grade metamorphic rock and felsic igneous rocks.

Table 2. Results of textural properties

Sample depth (ft)	Sorting	Grain size	Grain shape
2466	Poorly sorted to moderately sorted	Medium to Fine grained	Sub-angular to sub-rounded
2470	Moderately sorted	Medium grained	Angular
2479	Moderately sorted	Medium grained	Sub-rounded
2502	Well sorted	Fine grained	Angular
2524	Poorly sorted to moderately sorted	Medium to Fine grained	Sub-rounded to rounded
2538	Well sorted	Fine grained	Angular
2551	Well sorted	Fine grained	Rounded
2565	Moderately sorted to well sorted	Medium to fine grained	Sub-rounded to rounded
2574	Moderately sorted	Fine to very fine	Rounded
2586	Well sorted	Fine to very fine	Rounded

Table 3. Result of heavy minerals analysis and provenance inference

Heavy minerals	Provenance inference			
	Igneous rock		Metamorphic rock	
	Mafic	Felsic	High grade	Low grade
Zircon		Yes		
Hornblende		Yes	Yes	Yes
Glauconite		Yes		Yes

Fig. 3A depicts a crossplot establishing the relationship between porosity and quartz cementation. The cross plot clearly shows porosity values decreased with increase in quartz cementation. We can therefore establish a relationship between porosity and quartz cementation. At every point porosity is equal/not equal quartz cementation.

That is, porosity was never equal to quartz cementation at any point along the plot. These relationships go a long way in establishing the reservoir quality of HMU-well. It is also worthy to note that the porosity is preserved as a result of the coating of the sands by micro-quartz. They cover the surface of the grains, but this did not however prevent the growth of quartz or overgrowth, it only slows it down thereby preventing the destruction of the reservoir properties. While the relationship between intergranular volume spacing and matrix (Fig. 3B) shows that the grain matrix increases with increasing intergranular volume. This means that as the sands were subjected to compaction, the framework of the grains became locked.

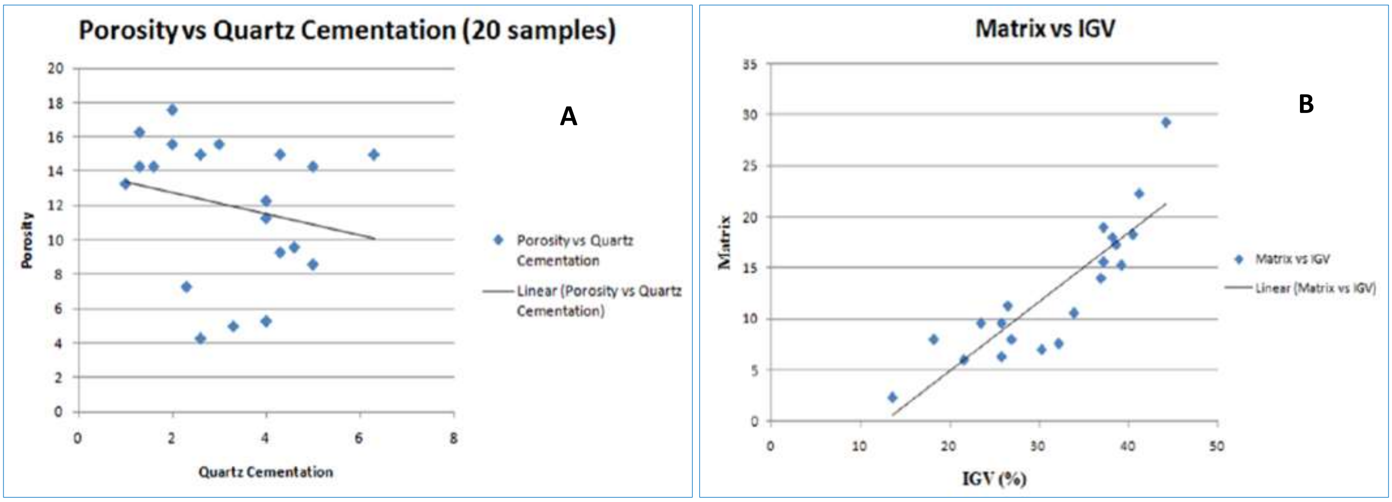


Fig. 3. (A) Cross plot of porosity against quartz cementation and (B): Matrix against intergranular volume

Consequently, porosity begins to decrease because of grain crushing, co-orientation and deformation. This process is enhanced due to the under compaction of the Niger Delta Basin where the study area lies. Under compaction is aided by early calcite or quartz cementation. The good sorting pattern is a reflection of the intergranular spaces. Grain size, sorting, shape and matrix content determine the initial space within the sand grains. As sediments increases with burial, these pore spaces decreases; this is a reflection of mechanical compaction. It causes the grain to pack closely together.

4.5. Environment of Deposition

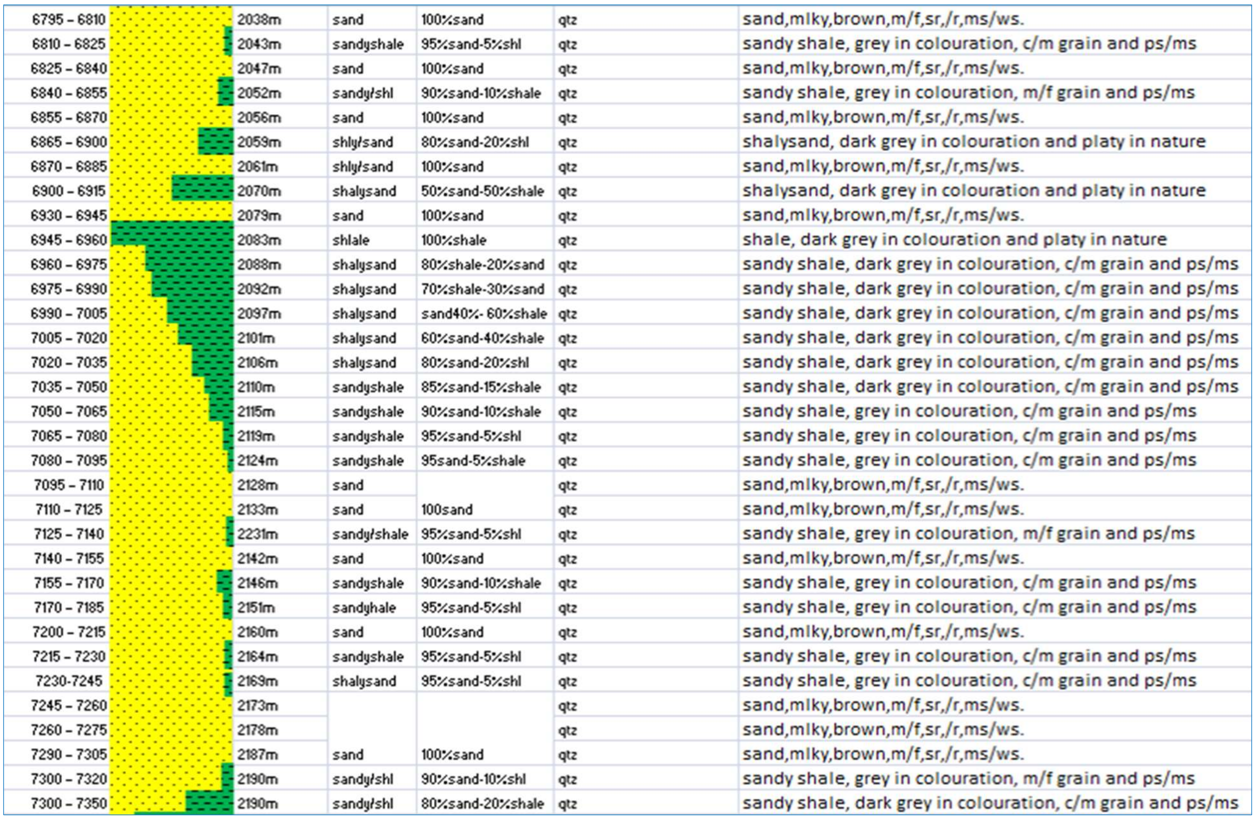
The environment of deposition was delineated using mainly the log signature as shown in (Figs. 4A-F). The lithology log displays mostly a fining upward sequence, a bell shape pattern indicative of a non-marine environment. The depositional system could be interpreted as fluvial. The coarse-grained basal sandstone facies consist of amalgamated and isolated sharp-based fining upward sand bodies characterized by blocky to bell-shaped Log motif. The sand units are locally separated by thin bands of shale/mudstone and lack marine fauna. The lithologic facies are interpreted as fluvial channel deposits based on these characteristics. These channel deposits represent deposition in a coastal plain setting landward of the tidal zone. The blocky log pattern is common in incised valley fills. The lack of serration in the lithology suggests minimal or complete absence of tidal influence.

Lithofacies Unit	sh-sand%	(m)	Litho-type	sand%-%shale	Mineral Assemblages	Sedimentological Description
5715 – 5730		1714m		100%sand	qtz and coal	sand,mlky,brown,c/m,sa,/sr,ps/ms.
5730 - 5745		1719m		100%sand	qtz and coal	sand,mlky,brown,c/m,sa,/sr,ps/ms.
5745 – 5760		1723m		100%sand	qtz and coal	sand,mlky,brown,c/m,sa,/sr,ps/ms.
5760 – 5775		1728m		100%sand	qtz and coal	sand,mlky,brown,c/m,sa,/sr,ps/ms.
5775 - 5790		1732m		100%sand	qtz and coal	sand,mlky,brown,c/m,sa,/sr,ps/ms.
5790 - 5805		1737m		100%sand	qtz and coal	sand,mlky,brown,c/m,sa,/sr,ps/ms.
5805 – 5820		1741m		100%sand	qtz and coal	sand,mlky,brown,c/m,sa,/sr,ps/ms.
5820 – 5835		1746m		100%sand	qtz and coal	sand,mlky,brown,c/m,sa,/sr,ps/ms.
5865 – 5880		1759m	sand	100%sand	qtz and coal	sand,mlky,brown,c/m,sa,/sr,ps/ms.
5880 – 5895		1764m	sandy/shl	15%sand-85%shal	qtz and coal	shalysand, dark grey in colouration and platy in nature
5895 – 5910		1768m	shly/sand	100%sand	qtz and coal	sand,mlky,brown,c/m,sa,/sr,ps/ms.
5910 – 5925		1773m	shale	60%sand-40%shale	qtz and coal	sandy shale, grey in colouration and platy in nature
5925 – 5940		1777m	sand	100%sand	qtz	sand,mlky,brown,c/m,sa,/sr,ps/ms.
5940 - 5955		1782m	sandy/shl	15%sand-85%shal	qtz	shalysand, dark grey in colouration and platy in nature
5955-5970		1786m	sandyshale	45%sand-55%shale	qtz	shalysand, dark grey in colouration and platy in nature
5970 – 5985		1791m	sand	100%sand	qtz and coal	sand,mlky,brown,c/m,sa,/sr,ps/ms.
5985 – 6000		1795m	shalysand	15%shale-85%sand	qtz	sandy shale, grey in colouration and platy in nature
6000 – 6015		1800m	sandy/shl	20%sand/80%shl	qtz	shalysand, dark grey in colouration and platy in nature
6015 – 6030		1804m	sandy/shl	15%sand/85%shl	qtz	sand,mlky,brown,c/m,sa,/sr,ps/ms.
6030 – 6045		1809m	sand	100%sand	qtz/ limonite	sand,mlky,brown,c/m,sa,/sr,ps/ms.
6045 – 6060		1813m	sand	100%sand	qtz	sand,mlky,brown,c/m,sa,/sr,ps/ms.
6060 – 6075		1818m	sand	100%sand	qtz/limonite	sand,mlky,brown,c/m,sa,/sr,ps/ms.
6075 – 6090		1822m	sand	100%sand	qtz	sand,mlky,brown,c/m,sa,/sr,ps/ms.
6105 – 6120		1831m	sandyshale	95%sand-5%shl	qtz	sandy shale, grey in colouration, c/m grain and ps/ms
6120 – 6135		1836m	sandyshale	100%sand	qtz	sand,mlky,brown,c/m,sa,/sr,ps/ms.
6135 – 6150		1840m	sandyshale	85%sand- 15%shl	qtz	sandy shale, grey in colouration, c/m grain and ps/ms
6150 – 6165		1845m	sandyshale	85%sand-15%shl	qtz	sandy shale, grey in colourationm c/m grain and ps/ms
6165 – 6180		1849m	shalysand	80%sand-20%shl	qtz	sandy shale, grey in colouration and platy in nature
6180 – 6195		1854m	sand	100%sand	qtz/ limonite	sand,mlky,brown,c/m,sa,/sr and ps/ms.
6210 – 6225		1863m	shalysand	50%shale-50%sand	qtz	shalysand, dark grey in colouration and platy in nature
6225-6240		1867m		100%sand	qtz/ limonite	sand,mlky,brown,m/f,sa,/sr,ms/ws.
6240 – 6255		1872m	shale	100%shale	qtz	sandy shale, dark grey in colouration and platy in nature

Fig. 4A. Lithostratigraphy analysis of samples from HMU-Well, Offshore, Western Niger Delta (5715ft - 6255ft)

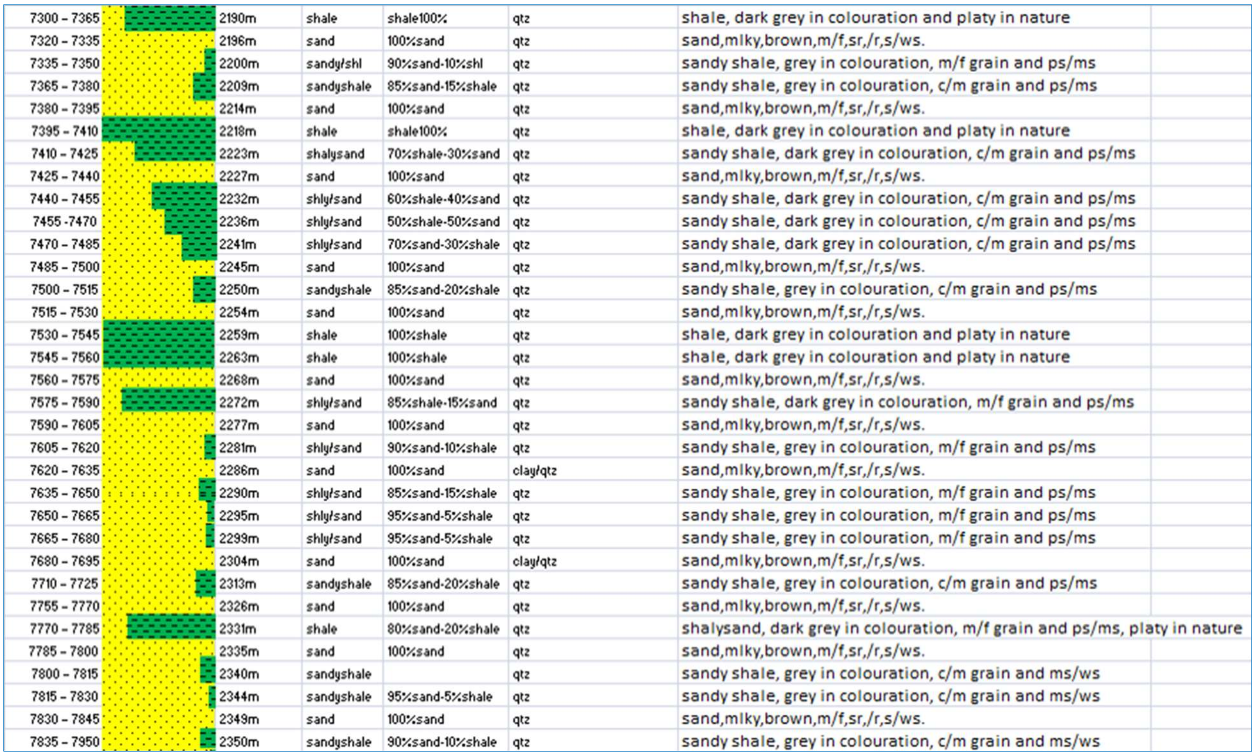
6270 – 6285		1881m	sand	100%sand	qtz	sand,mlky,brown,c/m,sa,/sr,ps/ms.
6285 – 6300		1885m	sand	100%sand	qtz	sand,mlky,brown,c/m,sa,/sr,ps/ms.
6300 – 6315		1890m	sand	100%sand	qtz	sand,mlky,brown,c/m,sa,/sr,ps/ms.
6315 – 6330		1894m	sand	100%sand	qtz	sand,mlky,brown,c/m,sa,/sr,ps/ms.
6330 – 6345		1899m	sand	100%sand	qtz	sand,mlky,brown,c/m,sa,/sr,ps/ms.
6345 – 6360		1903m	sand	100%sand	qtz	sand,mlky,brown,c/m,sa,/sr,ps/ms.
6360 – 6375		1908m	sand	100%sand	qtz/ limonite	sand,mlky,brown,c/m,sa,/sr,ps/ms.
6375 – 6390		1912m	sand	100%sand	qtz	sand,mlky,brown,c/m,sa,/sr,ps/ms.
6390 – 6405		1917m	sand	100%sand	qtz	sand,mlky,brown,c/m,sa,/sr,ps/ms.
6405 – 6420		1921m	sand	100%sand	qtz/ limonite	sand,mlky,brown,c/m,sa,/sr,ps/ms.
6420 – 6435		1926m	sand	100%sand	qtz	sand,mlky,brown,m/f,sr,/r,ms/ws.
6435 – 6450		1930m	shale	100%shale	qtz	shale, dark grey in colouration and platy in nature
6450 – 6465		1935m	shalysand	70%shale-30%sand	qtz	sandy shale, dark grey in colouration, c/m grain and ps/ms
6465 – 6480		1939m	shly/sand	60%shale-40%sand	qtz	sandy shale, dark grey in colouration, c/m grain and ps/ms
6480 – 6495		1944m	sandyshale	sand55%- 45%shale	qtz	sandy shale, dark grey in colouration, c/m grain and ps/ms
6495 -6510		1948m	sandyshale	60%sand-40%shale	qtz	sandy shale, dark grey in colouration, c/m grain and ps/ms
6510 – 6525		1953m	sandyshale	80%sand-20%shl	qtz	sandy shale, grey in colouration, c/m grain and ps/ms
6525 – 6540		1957m	sandyshale	85%sand-15%shale	qtz	sandy shale, grey in colouration, c/m grain and ps/ms
6540 – 6555		1962m	sandyshale	90%sand-10%shale	qtz	sandy shale, grey in colouration, c/m grain and ps/ms
6555 – 6570		1966m	sand	100%sand	qtz	sand,mlky,brown,m/f,sr,/r,ms/ws.
6570 – 6585		1971m	sand	100%sand	qtz	sand,mlky,brown,m/f,sr,/r,ms/ws.
6585 – 6600		1975m	sand	100%sand	qtz	sand,mlky,brown,m/f,sr,/r,ms/ws.
6600 – 6615		1980m	sandyshale	70%sand-30%shale	qtz	sandy shale, grey in colouration, c/m grain and ps/ms
6660 – 6675		1998m	sandyshale	55%sand-45%shale	qtz	sandy shale, grey in colouration, c/m grain and ps/ms
6675 – 6690		2002m	sandyshale	85%sand-15%shale	qtz	sandy shale, grey in colouration, c/m grain and ps/ms
6690 – 6705		2007m	sand	100%sand	qtz	sand,mlky,brown,m/f,sr,/r,ms/ws.
6690 – 6705		2007m	sandy/shale	95%sand-5%shl	qtz	sandy shale, grey in colouration, m/f grain and ps/ms
6705 – 6720		2011m	sandyshale		qtz	sand,mlky,brown,m/f,sr,/r,ms/ws.
6720 – 6735		2016m			qtz	sand,mlky,brown,m/f,sr,/r,ms/ws.
6735 – 6750		2020m	sand	100%sand	qtz	sand,mlky,brown,m/f,sr,/r,ms/ws.
6750 – 6765		2025m	sandyshale	95%sand-5%shl	qtz	sandy shale, grey in colouration, c/m grain and ps/ms
6765 – 6780		2029m	sand	100%sand	qtz	sand,mlky,brown,m/f,sr,/r,ms/ws.
6780 – 6795		2034m	sandyshale	95%sand-5%shale	qtz	sandy shale, grey in colouration, c/m grain and ps/ms

Fig. 4B. Lithostratigraphy analysis of samples from HMU-Well, Offshore, Western Niger Delta (6270ft - 6795ft)



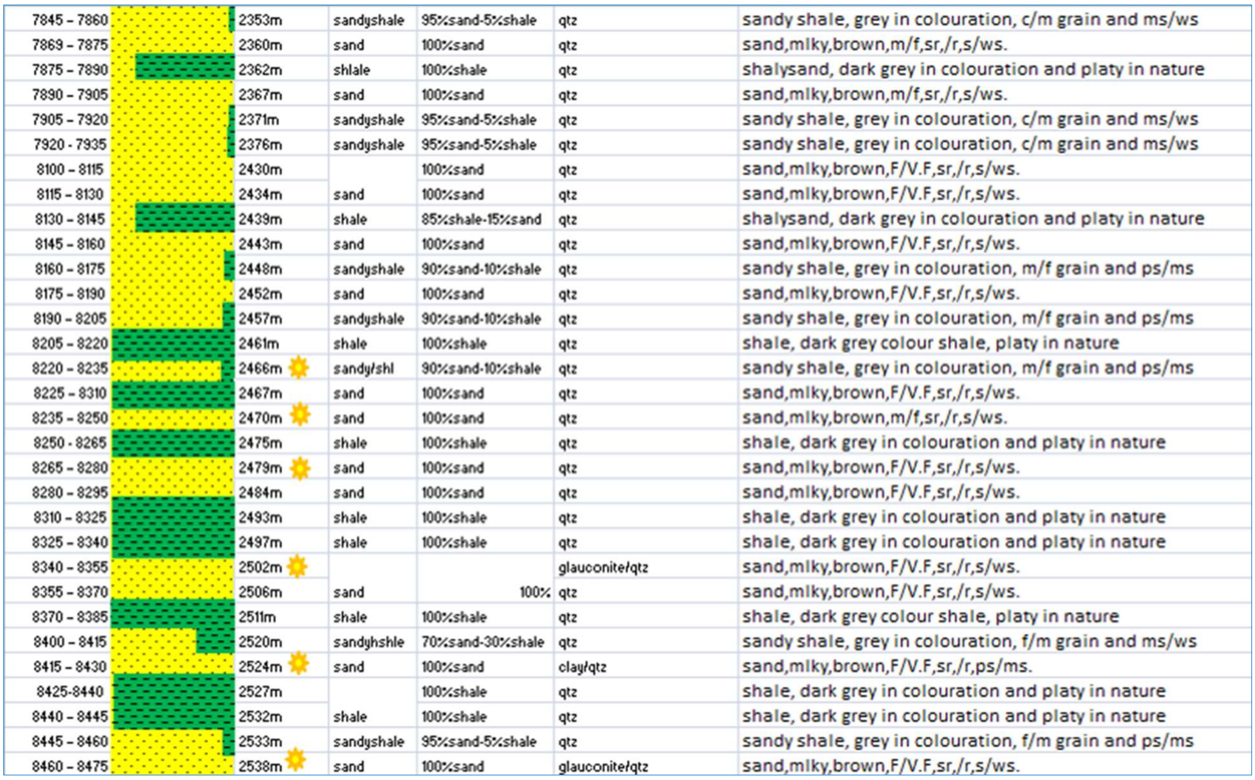
6795 – 6810	2038m	sand	100%sand	qtz	sand,mlky,brown,m/f,sr,/r,ms/ws.
6810 – 6825	2043m	sandyshale	95%sand-5%shl	qtz	sandy shale, grey in colouration, c/m grain and ps/ms
6825 – 6840	2047m	sand	100%sand	qtz	sand,mlky,brown,m/f,sr,/r,ms/ws.
6840 – 6855	2052m	sandy/shl	90%sand-10%shale	qtz	sandy shale, grey in colouration, m/f grain and ps/ms
6855 – 6870	2056m	sand	100%sand	qtz	sand,mlky,brown,m/f,sr,/r,ms/ws.
6865 – 6900	2059m	shly/sand	80%sand-20%shl	qtz	shalysand, dark grey in colouration and platy in nature
6870 – 6885	2061m	shly/sand	100%sand	qtz	sand,mlky,brown,m/f,sr,/r,ms/ws.
6900 – 6915	2070m	shalysand	50%sand-50%shale	qtz	shalysand, dark grey in colouration and platy in nature
6930 – 6945	2079m	sand	100%sand	qtz	sand,mlky,brown,m/f,sr,/r,ms/ws.
6945 – 6960	2083m	shlale	100%shale	qtz	shale, dark grey in colouration and platy in nature
6960 – 6975	2088m	shalysand	80%shale-20%sand	qtz	sandy shale, dark grey in colouration, c/m grain and ps/ms
6975 – 6990	2092m	shalysand	70%shale-30%sand	qtz	sandy shale, dark grey in colouration, c/m grain and ps/ms
6990 – 7005	2097m	shalysand	sand40%- 60%shale	qtz	sandy shale, dark grey in colouration, c/m grain and ps/ms
7005 – 7020	2101m	shalysand	60%sand-40%shale	qtz	sandy shale, dark grey in colouration, c/m grain and ps/ms
7020 – 7035	2106m	shalysand	80%sand-20%shl	qtz	sandy shale, dark grey in colouration, c/m grain and ps/ms
7035 – 7050	2110m	sandyshale	85%sand-15%shale	qtz	sandy shale, dark grey in colouration, c/m grain and ps/ms
7050 – 7065	2115m	sandyshale	90%sand-10%shale	qtz	sandy shale, grey in colouration, c/m grain and ps/ms
7065 – 7080	2119m	sandyshale	95%sand-5%shl	qtz	sandy shale, grey in colouration, c/m grain and ps/ms
7080 – 7095	2124m	sandyshale	95sand-5%shale	qtz	sandy shale, grey in colouration, c/m grain and ps/ms
7095 – 7110	2128m	sand		qtz	sand,mlky,brown,m/f,sr,/r,ms/ws.
7110 – 7125	2133m	sand	100sand	qtz	sand,mlky,brown,m/f,sr,/r,ms/ws.
7125 – 7140	2231m	sandy/shale	95%sand-5%shl	qtz	sandy shale, grey in colouration, m/f grain and ps/ms
7140 – 7155	2142m	sand	100%sand	qtz	sand,mlky,brown,m/f,sr,/r,ms/ws.
7155 – 7170	2146m	sandyshale	90%sand-10%shale	qtz	sandy shale, grey in colouration, c/m grain and ps/ms
7170 – 7185	2151m	sandyhale	95%sand-5%shl	qtz	sandy shale, grey in colouration, c/m grain and ps/ms
7200 – 7215	2160m	sand	100%sand	qtz	sand,mlky,brown,m/f,sr,/r,ms/ws.
7215 – 7230	2164m	sandyshale	95%sand-5%shl	qtz	sandy shale, grey in colouration, c/m grain and ps/ms
7230-7245	2169m	shalysand	95%sand-5%shl	qtz	sandy shale, grey in colouration, c/m grain and ps/ms
7245 – 7260	2173m			qtz	sand,mlky,brown,m/f,sr,/r,ms/ws.
7260 – 7275	2178m			qtz	sand,mlky,brown,m/f,sr,/r,ms/ws.
7290 – 7305	2187m	sand	100%sand	qtz	sand,mlky,brown,m/f,sr,/r,ms/ws.
7300 – 7320	2190m	sandy/shl	90%sand-10%shl	qtz	sandy shale, grey in colouration, m/f grain and ps/ms
7300 – 7350	2190m	sandy/shl	80%sand-20%shale	qtz	sandy shale, dark grey in colouration, c/m grain and ps/ms

Fig. 4C. Lithostratigraphy analysis of samples from HMU-Well, Offshore, Western Niger Delta (6735ft - 7350ft)



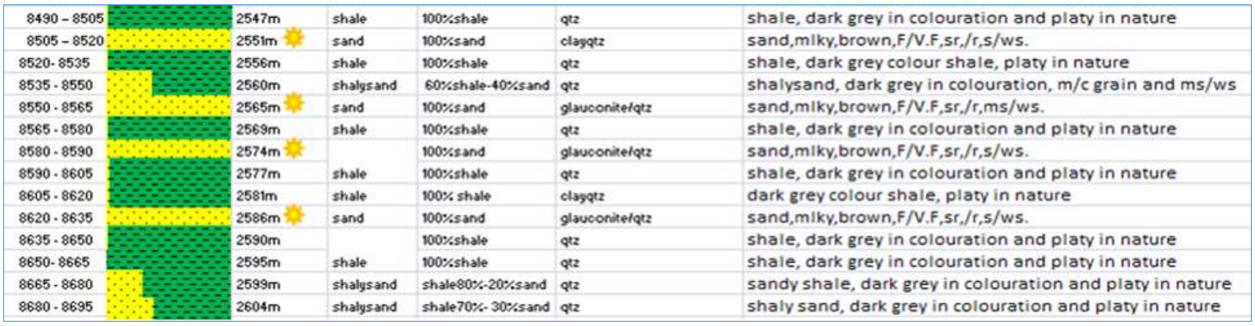
7300 – 7365	2190m	shale	shale100%	qtz	shale, dark grey in colouration and platy in nature
7320 – 7335	2196m	sand	100%sand	qtz	sand,mlky,brown,m/f,sr,/r,s/ws.
7335 – 7350	2200m	sandy/shl	90%sand-10%shl	qtz	sandy shale, grey in colouration, m/f grain and ps/ms
7365 – 7380	2209m	sandyshale	85%sand-15%shale	qtz	sandy shale, grey in colouration, c/m grain and ps/ms
7380 – 7395	2214m	sand	100%sand	qtz	sand,mlky,brown,m/f,sr,/r,s/ws.
7395 – 7410	2218m	shale	shale100%	qtz	shale, dark grey in colouration and platy in nature
7410 – 7425	2223m	shalysand	70%shale-30%sand	qtz	sandy shale, dark grey in colouration, c/m grain and ps/ms
7425 – 7440	2227m	sand	100%sand	qtz	sand,mlky,brown,m/f,sr,/r,s/ws.
7440 – 7455	2232m	shly/sand	60%shale-40%sand	qtz	sandy shale, dark grey in colouration, c/m grain and ps/ms
7455 -7470	2236m	shly/sand	50%shale-50%sand	qtz	sandy shale, dark grey in colouration, c/m grain and ps/ms
7470 – 7485	2241m	shly/sand	70%sand-30%shale	qtz	sandy shale, dark grey in colouration, c/m grain and ps/ms
7485 – 7500	2245m	sand	100%sand	qtz	sand,mlky,brown,m/f,sr,/r,s/ws.
7500 – 7515	2250m	sandyshale	85%sand-20%shale	qtz	sandy shale, grey in colouration, c/m grain and ps/ms
7515 – 7530	2254m	sand	100%sand	qtz	sand,mlky,brown,m/f,sr,/r,s/ws.
7530 – 7545	2259m	shale	100%shale	qtz	shale, dark grey in colouration and platy in nature
7545 – 7560	2263m	shale	100%shale	qtz	shale, dark grey in colouration and platy in nature
7560 – 7575	2268m	sand	100%sand	qtz	sand,mlky,brown,m/f,sr,/r,s/ws.
7575 – 7590	2272m	shly/sand	85%shale-15%sand	qtz	sandy shale, dark grey in colouration, m/f grain and ps/ms
7590 – 7605	2277m	sand	100%sand	qtz	sand,mlky,brown,m/f,sr,/r,s/ws.
7605 – 7620	2281m	shly/sand	90%sand-10%shale	qtz	sandy shale, grey in colouration, m/f grain and ps/ms
7620 – 7635	2286m	sand	100%sand	clay/qtz	sand,mlky,brown,m/f,sr,/r,s/ws.
7635 – 7650	2290m	shly/sand	85%sand-15%shale	qtz	sandy shale, grey in colouration, m/f grain and ps/ms
7650 – 7665	2295m	shly/sand	95%sand-5%shale	qtz	sandy shale, grey in colouration, m/f grain and ps/ms
7665 – 7680	2299m	shly/sand	95%sand-5%shale	qtz	sandy shale, grey in colouration, m/f grain and ps/ms
7680 – 7695	2304m	sand	100%sand	clay/qtz	sand,mlky,brown,m/f,sr,/r,s/ws.
7710 – 7725	2313m	sandyshale	85%sand-20%shale	qtz	sandy shale, grey in colouration, c/m grain and ps/ms
7755 – 7770	2326m	sand	100%sand	qtz	sand,mlky,brown,m/f,sr,/r,s/ws.
7770 – 7785	2331m	shale	80%sand-20%shale	qtz	shalysand, dark grey in colouration, m/f grain and ps/ms, platy in nature
7785 – 7800	2335m	sand	100%sand	qtz	sand,mlky,brown,m/f,sr,/r,s/ws.
7800 – 7815	2340m	sandyshale		qtz	sandy shale, grey in colouration, c/m grain and ms/ws
7815 – 7830	2344m	sandyshale	95%sand-5%shale	qtz	sandy shale, grey in colouration, c/m grain and ms/ws
7830 – 7845	2349m	sand	100%sand	qtz	sand,mlky,brown,m/f,sr,/r,s/ws.
7835 – 7950	2350m	sandyshale	90%sand-10%shale	qtz	sandy shale, grey in colouration, c/m grain and ms/ws

Fig. 4D. Lithostratigraphy analysis of samples from HMU-Well, Offshore, Western Niger Delta (7300ft - 7950ft)



7845 – 7860	2353m	sandyshale	95%sand-5%shale	qtz	sandy shale, grey in colouration, c/m grain and ms/ws
7869 – 7875	2360m	sand	100%sand	qtz	sand,mlky,brown,m/f,sr,/r,s/ws.
7875 – 7890	2362m	shlale	100%shale	qtz	shalysand, dark grey in colouration and platy in nature
7890 – 7905	2367m	sand	100%sand	qtz	sand,mlky,brown,m/f,sr,/r,s/ws.
7905 – 7920	2371m	sandyshale	95%sand-5%shale	qtz	sandy shale, grey in colouration, c/m grain and ms/ws
7920 - 7935	2376m	sandyshale	95%sand-5%shale	qtz	sandy shale, grey in colouration, c/m grain and ms/ws
8100 – 8115	2430m		100%sand	qtz	sand,mlky,brown,F/V.F,sr,/r,s/ws.
8115 – 8130	2434m	sand	100%sand	qtz	sand,mlky,brown,F/V.F,sr,/r,s/ws.
8130 – 8145	2439m	shale	85%shale-15%sand	qtz	shalysand, dark grey in colouration and platy in nature
8145 – 8160	2443m	sand	100%sand	qtz	sand,mlky,brown,F/V.F,sr,/r,s/ws.
8160 – 8175	2448m	sandyshale	90%sand-10%shale	qtz	sandy shale, grey in colouration, m/f grain and ps/ms
8175 – 8190	2452m	sand	100%sand	qtz	sand,mlky,brown,F/V.F,sr,/r,s/ws.
8190 – 8205	2457m	sandyshale	90%sand-10%shale	qtz	sandy shale, grey in colouration, m/f grain and ps/ms
8205 – 8220	2461m	shale	100%shale	qtz	shale, dark grey colour shale, platy in nature
8220 – 8235	2466m	sandy/shl	90%sand-10%shale	qtz	sandy shale, grey in colouration, m/f grain and ps/ms
8225 – 8310	2467m	sand	100%sand	qtz	sand,mlky,brown,F/V.F,sr,/r,s/ws.
8235 – 8250	2470m	sand	100%sand	qtz	sand,mlky,brown,m/f,sr,/r,s/ws.
8250 - 8265	2475m	shale	100%shale	qtz	shale, dark grey in colouration and platy in nature
8265 – 8280	2479m	sand	100%sand	qtz	sand,mlky,brown,F/V.F,sr,/r,s/ws.
8280 – 8295	2484m	sand	100%sand	qtz	sand,mlky,brown,F/V.F,sr,/r,s/ws.
8310 – 8325	2493m	shale	100%shale	qtz	shale, dark grey in colouration and platy in nature
8325 – 8340	2497m	shale	100%shale	qtz	shale, dark grey in colouration and platy in nature
8340 – 8355	2502m			glauconite/qtz	sand,mlky,brown,F/V.F,sr,/r,s/ws.
8355 – 8370	2506m	sand	100%	qtz	sand,mlky,brown,F/V.F,sr,/r,s/ws.
8370 – 8385	2511m	shale	100%shale	qtz	shale, dark grey colour shale, platy in nature
8400 – 8415	2520m	sandyhshle	70%sand-30%shale	qtz	sandy shale, grey in colouration, f/m grain and ms/ws
8415 – 8430	2524m	sand	100%sand	clay/qtz	sand,mlky,brown,F/V.F,sr,/r,ps/ms.
8425-8440	2527m		100%shale	qtz	shale, dark grey in colouration and platy in nature
8440 – 8445	2532m	shale	100%shale	qtz	shale, dark grey in colouration and platy in nature
8445 – 8460	2533m	sandyshale	95%sand-5%shale	qtz	sandy shale, grey in colouration, f/m grain and ps/ms
8460 – 8475	2538m	sand	100%sand	glauconite/qtz	sand,mlky,brown,F/V.F,sr,/r,s/ws.

Fig. 4E. Lithostratigraphy analysis of samples from HMU-Well, Offshore, Western Niger Delta (7845ft - 8475ft)



8490 – 8505	2547m	shale	100%shale	qtz	shale, dark grey in colouration and platy in nature
8505 – 8520	2551m	sand	100%sand	clayqtz	sand,mlky,brown,F/V.F,sr,/r,s/ws.
8520- 8535	2556m	shale	100%shale	qtz	shale, dark grey colour shale, platy in nature
8535 - 8550	2560m	shalysand	60%shale-40%sand	qtz	shalysand, dark grey in colouration, m/c grain and ms/ws
8550 - 8565	2565m	sand	100%sand	glauconite/qtz	sand,mlky,brown,F/V.F,sr,/r,ms/ws.
8565 - 8580	2569m	shale	100%shale	qtz	shale, dark grey in colouration and platy in nature
8580 - 8590	2574m		100%sand	glauconite/qtz	sand,mlky,brown,F/V.F,sr,/r,s/ws.
8590 - 8605	2577m	shale	100%shale	qtz	shale, dark grey in colouration and platy in nature
8605 - 8620	2581m	shale	100% shale	clayqtz	dark grey colour shale, platy in nature
8620 - 8635	2586m	sand	100%sand	glauconite/qtz	sand,mlky,brown,F/V.F,sr,/r,s/ws.
8635 - 8650	2590m		100%shale	qtz	shale, dark grey in colouration and platy in nature
8650- 8665	2595m	shale	100%shale	qtz	shale, dark grey in colouration and platy in nature
8665 - 8680	2599m	shalysand	shale80%-20%sand	qtz	sandy shale, dark grey in colouration and platy in nature
8680 - 8695	2604m	shalysand	shale70%- 30%sand	qtz	shaly sand, dark grey in colouration and platy in nature

Fig. 4F. Lithostratigraphy analysis of samples from HMU-Well, Offshore, Western Niger Delta (8490ft - 8695ft)

5. Conclusion

The reservoir quality of the rocks in the HMU-Well has delineated using parameters such Pickett cross plots, heavy mineral analysis, well log signature, index of chemical maturity, diagenetic process, (cementation and compaction), petrographic analysis and textural properties. The reservoir quality is good and sands are both texturally and mineralogically matured. The porosity of the reservoir sand bodies is fine to medium. The presence of cementing materials acts as barrier to vertical flow of fluids. Porosity is however preserved by other processes such as coating of the grains by micro-quartz. This slows down the effect of cementation. Finally, we can conclude that the reservoir sand bodies of HMU-Well are good and will yield maximum output on production. The environment of deposition is marine environment as indicated by the lithologic model which is mostly fining upwards sequence (FUS).

6. Recommendations

Well log suite should be provided and integrated with the present study to determine the lateral extent of the textural, petrophysical and diagenetic properties.

Bio-data should be made available for palynological analysis to determine the paleo-environments using marker fossils on HMU-Well to create a correlation panel tied with core data.

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