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Lithofacies Analysis and Qualitative Minerology of the Sediments of #3 Well in the Greater Ughelli Depobelt, Niger Delta Basin

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Abstract

The sediment of #3 Well of the Greater Ughelli Depobelt are represented by sand and shale intercalation. In this study, lithofacies analysis and X-ray diffraction technique were used to characterize the sediments from the well. The lithofacies analysis was based on the physical properties of the sediments encountered from the ditch cuttings. Five lithofacies types of mainly sandstone, clayey sandstone, shaly sandstone, sandy shale and shale and 53 lithofacies zones were identified from 15 ft to 11295 ft. The result of the X-ray diffraction analysis identified that the following clay minerals – kaolinite, illite/muscovite, sepiolite, chlorite, calcite, dolomite; with kaolinite in greater percentage. The non-clay minerals include quartz, pyrite, anatase, gypsum, plagioclase, microcline, jarosite, barite and fluorite; with quartz having the highest percentage. Therefore, due to the high percentage of kaolinite in #3 well, the pore filing kaolinite may have more effect on the reservoir quality than illite/muscovite, chlorite and sepiolite. By considering the physical properties, homogenous and heterogeneous nature of the #3 Well, it would be concluded that #3 Well has some prospect for petroleum and gas exploration.

Keywords: Intercalation; X-ray diffraction; Reservoir; Mineralogy; Exploration.

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1. Introduction

1.1. Background of study

The stratigraphy of the Niger Delta and its associated mineral are important for hydrocarbon exploration. Exploration and exploitation of the delta started in 1956 [1]. The delta is a prolific basin that is known to provide source and reservoir rocks for hydrocarbon production.

Mineralogy has been used as a tool in predicting paleo-environment, reservoir quality and hydrocarbon bearing formations [2]. Clay mineral has also been used for petroleum system analysis and to determine oil and gas entrapment time [3]. The maturation and migration of hydrocarbon requires the interplay of some geologic conditions that will

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favour the accumulation of hydrocarbon. These conditions include the distribution of source rock, reservoir rock, sealing mechanism, migration pathways and timing; these conditions are regarded to as hydrocarbon play elements. The hydrocarbon play elements distribution in the basin is a result of the tectonic history and basin fill [4]. Lithofacies characterization and quantitative mineralogy have been carried out in the Northern Depobelt of the Niger Delta to identify the rock types and clay minerals present [5].

Lithofacies analysis and quantitative mineralogy were undertaken in order to characterize the rock types and determine the quantitative amount of the clay minerals which hitherto have not been used by any researcher in the Greater Ughelli Depobelt. This study will provide up to date information on the quality of the source rock, reservoir rock and the quality of the hydrocarbon play elements. The study area is located in the Greater Ughelli Depobelt of the Niger Delta Basin. The well is geographically located between latitude 5°30N and longitude 5° 45E (Fig. 1).

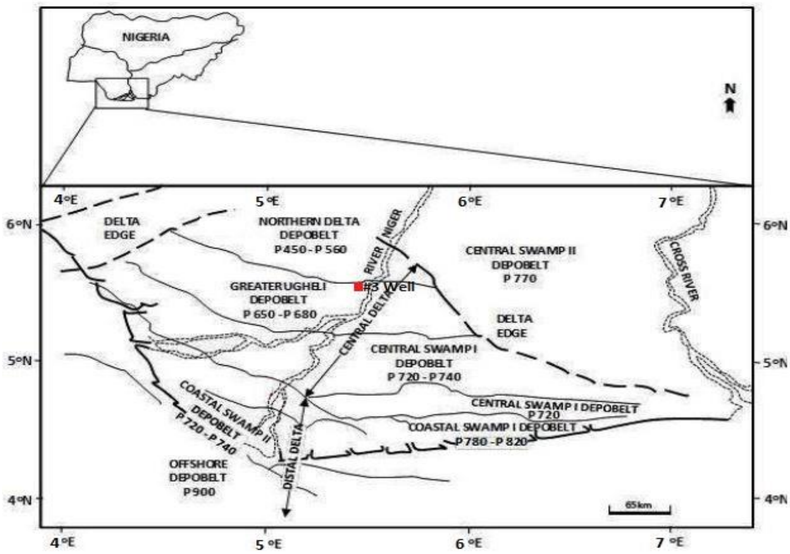

Fig. 1. Location map of study area [6].

1.2 Geologic setting

The evolution of Niger Delta started during the Aptian times, the region presently occupied by the Niger Delta Bain was the failed armed of the R-R-R (ridge-ridge-ridge) triple junction that led up the separation of South American from Africa [7]. The evolution of the Tertiary Niger delta basin occurred in three phases [8]. They are: Pre -Santonian basin evolution, Santonian - Paleocene basin evolution and the Eocene - Recent delta phase.

During the Pre - Santonian basin evolution, the oldest pre tertiary sedimentary basin is the Benue Abakaliki Trough, which originated as an aulacogen (failed arm) of the triple –

ridge system that led up the separation of South American from Africa in the Aptian times [7]. The three arms of the triple junction opened at different rates and times. During the mid – Aptian in the south Atlantic, the opening was accompanying by crustal stretching and down – warping followed by the development of coastal evaporate basin [9]. By lower Albian, the rifting has reached the Gulf of Guinea and extended northeast to form the Benue – Abakaliki Trough. The Benue Trough is filled by over 3,300 km of sediments of Albian to Coniacian age and then begun to close, followed by possible crustal subduction [10]. Consequent to the Campano – Santonian tectonic folding during the Santonian-Paleocene phase, the Benue-Abakaliki Trough was uplifted to form the Abakaliki High, while the Anambra platform down warped to give rise to the Anambra basin. The sea then encroached upon the Benin flank basement, adjoining the Anambra basin for the first time. There exist three sedimentary basins from the Campanian to the Paleocene; the Anambra basin, the Afikpo Syncline and the under formed Ikang Trough. Eocene to Recent Phase was initiated in response to the epirogenic movement along the Benin and Calabar flanks and continued to build up the Niger Delta, up till present time. This stage was marked by regression that is frequently interrupted by minor transgression [11]. The age of the sediments in the Greater Ughelli Depobelt using index markers ranges from Oligocene to Miocene epoch [12]. Depositional environment for the sediments in the Greater Ughelli depobelt ranges from marginal marine environment (littoral zone) to shallow marine environment (inner neritic zone) [13].

The Niger Delta is divided into three major stratigraphic units, which are the Akata, Agbada and Benin Formations [14]. The three formations occur in each of five offlapping siliciclastic sedimentation cycles that comprise the depobelts [15,16]. Table 1 shows the stratigraphy of the Niger Delta.

Table 1. Age and Formations of the Niger Delta Sedimentary Basin (modified after [17,18]).

SUBSURFACE			SURFACE OUTCROP		
YOUNGEST KNOWN AGE	FORMATION	OLDEST KNOWN AGE	YOUNGEST KNOWN AGE	FORMATION	OLDEST KNOWN AGE
Recent	Benin Fm.	Oligocene	Holocene	Alluvium	Miocene?
			Ear. Holo. To Late Pleistoc.	Deltaic Plain Deposits	
	Afam Shale Member		Plio. / Pleist.	Benin Fm.	
Recent	Agbada Fm.	Eocene	Miocene	Ogwashi - Asaba Fm.	Oligocene
			Eocene	Ameki Fm.	Eocene
Recent	Akata Fm.	Eocene	L. Eocene	Imo Shale	Paleocene
	Imo Shale	Paleocene	Paleocene	Nsukka Fm.	Maestrich.
	Nsukka Fm.	Maestrich.	Maestrich.	Ajali Fm.	Maestrich.
	Equivalent not known		Campanian	Mamu Fm.	Campanian
			Camp./ Mae.	Nkporo Sh.	Santonian
			Conia/ Santo.	Agwu Shale	Turonian
			Turonian	Ezeaku Shale	Turonian
			Albian	Asu River Gp.	Albian

2. Materials and Methods

A total of 697 ditch cutting samples selected between the intervals of 15 ft to 11295 ft from #3 Well were taken for lithofacies analysis. Ditch cutting samples from the well were examined visually and under the reflected light microscope to determine the different lithology by considering the colour, texture (grain size, roundness, shape and sorting), mineral types and accessories such as quartz, mica, iron oxide, pyrite and carbonaceous detritus. The presence of carbonate in the sediments was tested for with 10 % of diluted hydrochloric acid. Effervescence indicates carbonate presence. Lithologic log was generated from the lithofacies description of the entire ditch cutting from the well.

Eight ditch cutting samples from the well were selected from the shaly and sandy shale interval of interest for XRD preparation technique. The ditch cutting samples were milled and prepared using the back loading preparation technique. The prepared samples were placed into the panalytical aeris diffractometer for analysis. In the course of the analysis the phases were identified using X-pert highscore plus software and the relative amount (weight %) were estimated using the Rietveld method.

3. Results and Discussion

3.1. *Lithofacies analysis*

The lithofacies analysis for #3 Well allowed the identification of 53 lithofacies zones which include 15 homogenetic zones and 38 heterogenetic zones. Five lithofacies types which include sandstone, clayey sandstone, shaly sandstone, sandy shale and shale were identified the well (Fig. 2). Minerals identified in this well include quartz, iron oxide, pyrite, carbonate, mica flakes and plant rootlets.

3.1.1. *Lithofacies analysis of lithofacies zones*

Lithofacies zone 1 to 8 (Benin Formation): This Lithofacies zones occur within the interval of 15 ft to 6030 ft. It consists of eight lithofacies zones with 4 homogenous zones and 4 heterogenous zones. The grains are mainly whitish to yellowish sandstones. The grains vary from very fine sand to granules, angular to well-rounded and poorly sorted to very well sorted. Minerals found within this zone include iron oxide, mica, pyrite and carbonate. Coal is present within these lithofacies zones which ranges from 10 to 90 %. Thin laminae of shale are found occasional within this the sand body. Based on the percentage of the intercalation of shale to sand ratio, a continental environment is given to these lithofacies zones [19].

Lithofacies zone 9 to 53 (Agbada Formation): This lithofacies zones occur within the interval of 6060 ft to11295 ft. It consists of 45 lithofacies zone with 10 homogenous zones and 35 heterogenous zones with mainly yellowish sandstone. This zone consists of intercalation of sand and shale with mainly sandstone and shaly sandstone at the top; and sandy shale and shale at the base. The shale is greyish in color, fine grained with fissility which is an indicative of calm and an anoxic condition. Sand, granule, pebble, cobble and boulder are also found in this lithofacies zones. The minerals found within this zone include mica, iron oxide, pyrite and clay. Rootlets and wood fragments also occur in this lithofacies zone. Based on the percentage of the intercalation of shale to sand ratio, a paralic to continental environment is given to these lithofacies zones [19].

Depth (ft)	Mineral	Lithology	Lithozone	Homogenetic zone	Heterogenetic zone	Sh- Sd%	Sedimentologic Descripion	Environent	Formation
15-30			Zone 1	1			Whitish,medium to granule grained, sub angular to subrounded, poorly sorted, 10% coal	Continental	Benin
30-4345	Iron-oxide		Zone 2		1	10%-90%	Whitish to yellowish, medium to granules grained, angular to rounded, poorly to well sorted, 5 to 10 % clay, coal		
4345-4365	Iron-oxide		Zone 3		2	40%-60%	Grey, fine to coarse grained, subangular to subrounded, moderately sorted, 20 % coal		
4365-6030	Pyrite. Mica		Zone 4	2			Whitish, fine to granules grained, v. angu. to rounded, poorly to well sorted, clay, rootlets, wood fragm., shell, 0-80 % coal		
6030-6060	Iron-oxide		Zone 5		3	30%-70%	Grey, v. fine to v. coarse grained, angular to well rounded, moderately to well sorted, friable, wood fragments, coal		
6060-6090	Iron-oxide		Zone 6	3			Whitish, medium to granule grained, subang. to rounded, mod. to well sorted, clay, rootlets, wood fragments, 10 % coal	Paralic - Transitional	Agbada Formation
6090-6375	Pyrite		Zone 7		4	10%-90%	Grey, fine to granules grained, ang. to well rounded, mod. to well sorted, clay, rootlets, wood fragments, 0 -5% coal		
6375-6765	Iron-oxide		Zone 8	4			Whitish, very fine to granules grained, angular to well rounded, moderately to well sorted, clay, 0 to 5% coal		
6765-7140			Zone 9		5	20%-80%	Grey, very fine to very coarse grained, subangular to well rounded, poorly to well sorted, clay, 0- 5% coal		
7140-7155	Iron-oxide		Zone 10		6	60%-40%	Grey, very fine grained with fissile		
7155-8100	Iron-oxide		Zone 11		7	40%-60%	Grey, very fine to granules grained, angl. to well rounded, poorly to well sorted, friable grain, clay, rootlets, coal		
8100-8130	Pyrite, mica		Zone 12		8	60%-40%	Grey, very fine grained , 5-10% coal		
8130-8265			Zone 13		9	40%-60%	Grey, very fine to coarse grained, very angular to rounded, poorly to moderately sorted, rootlets, 0-5 % coal		
8265-8310	Iron-oxide		Zone 14		10	55%-45%	Grey, fine to coarse grained, angular to rounded, poorly sorted, 0-5 % coal		
8310-8400	Iron-oxide		Zone 15		11	30%-70%	Grey, fine to granule grained, very angular to rounded, poorly to moderately sorted, 0-5 % coal		
8400-8430	mica		Zone 16		12	70%-30%	Grey, fine grained, fissile with coal		
8430-8585	Carbonate		Zone 17		13	40%-60%	Grey, fine to very coarse grained, angular to rounded, friable grain, poorly to moderately sorted, 0-5% coal		
8535-8625			Zone 18		14	65%-35%	Grey, fine grained with fissile, 30- 40 % sand, coal		
8625-8760			Zone 19		15	45%-55%	Grey, fine to v. coarse grained, angular to rounded, poorly to moderately sorted, with 25-45 % shale, 10-15% coal		
8760-8775			Zone 20		16	55%-45%	Grey, fine grained and fissile, 5 % coal		
8775-8895			Zone 21		17	45%-55%	Grey, fine to granule grained, angular to rounded, moderately sorted, 0-5 % coal		
8895-8940			Zone 22		18	60%-40%	Grey, fine grained and fissile, 40 % sand, coal		
8940-8955	Iron-oxide		Zone 23		19	40%-60%	Light Grey, medium to granule grained, angular to subrounded, poorly sorted, coal		
8955-9015			Zone 24		20	65%-35%	Grey, fine grained and fissile, 35- 40% sand, coal		
9015-9195	Pyrite		Zone 25		21	35%-65%	Grey, fine to very coarse grained, angular to rounded, poorly sorted, 0- 40% coal		
9195-9210	mica		Zone 26	5			Grey, medium to coarse grained, subangular to subrounded, poorly sorted, 90 % coal		
9210-9255			Zone 27		22	25%-75%	Grey, fine to very coarse grained, subangular to subrounded, poorly to moderately sorted, 0 - 40 % coal		
9255-9270			Zone 28		23	60%-40%	Grey, fine grained and fissile, 40 % sand		
9270-9285			Zone 29		24	40%-60%	Light grey, fine to very coarse grained, subangular to subrounded, moderately sorted, coal		
9285-9315			Zone 30		25	70%-30%	Grey, fine grained and fissile, 30 % coal		
9315-9420			Zone 31		26	40%-60%	Grey, fine to coarse grained, angular to subrounded, poorly to moderately sorted, 40 - 45% shale, coal		
9420-9435	Iron-oxide		Zone 32		27	60%-40%	Grey, fine grained and fissile, 40 % sand, coal		
9435-9465	Iron-oxide		Zone 33		28	45%-55%	Grey, fine to very coarse grained, angular to subrounded, poorly sorted, coal		
9465-10140			Zone 34		29	55%-45%	Grey, fine grained and fissile, 5 -45 % sand, coal		
10140-10170			Zone 35	6			Grey, fine grained and fissile, coal		
10170-10260			Zone 36		30	80%-20%	Grey, fine grained and fissile, 5 - 40 % sand, coal		
10260-10320			Zone 37	7			Grey, fine grained and fissile, coal		
10320-10515	Iron-oxide		Zone 38		31	95%-5%	Grey, fine grained and fissile, 5 - 30 % sand, 0 - 40 % coal.		
10515-10605	Pyrite, mica		Zone 39	8			Grey, fine grained and fissile, coal		
10605-10620			Zone 40		32	95%-5%	Grey, fine grained, 0-10 % coal		
10620-10710	Iron-oxide		Zone 41	9			Grey, fine grained and fissile, 5 - 10 % coal		
10710-10755			Zone 43		33	95%-5%	Grey, fine grained and fissile, 5 % sand, coal		
10755-10830			Zone 44	10			Grey, fine grained and fissile, coal		
10830-10860			Zone 45		34	95%-5%	Grey, fine grained and fissile, 5 % sand, coal		
10860-10995	Iron-oxide		Zone 46	11			Grey, fine grained and fissile, 0- 5 % coal		
10995-11010			Zone 47		35	95%-5%	Grey, fine grained and fissile, 0 - 7 % coal		
11010-11025			Zone 48	12			Grey, fine grained		
11025-11115			Zone 49		36	90%-10%	Grey, fine grained , 5 - 10 % sand, 5 -40 % coal		
11115-11130			Zone 50	13			Grey, fine grained with coal		
11130-11265			Zone 51		37	95%-5%	Grey, fine grained with fissility, 5 - 10 % sand, coal		
11265-11295			Zone 52	14			Grey, fine grained with fissility, coal		
11295			Zone 53		38	95%-5%	Grey, fine grained with fissility, 5 - 10 % sand , coal		

Fig. 2. Lithostratigraphic model for #3 Well.

3.2. *Mineralogy*

The mudrocks from the #3 Well of the Greater Ughelli Depobelt constitute significance source rock and seal for the hydrocarbon trapped in the sandstone reservoir rock of the well. The prediction of the reservoir characteristics has become a major challenge for hydrocarbon exploration and development. An understanding of the mudrocks is important in understanding the characteristics of the reservoir and the oil recovery efficiency. Quartz and clay minerals are the predominant minerals that constitute the whole rock mineral assemblages of the mudrocks.

3.2.1. *Clay minerals*

The total clay mineral content of the whole-rock mineral assemblage varies between 0.35 % to 34.48 %; the total clay mineral could be as low as 0.35 % reflecting a relatively high silt component. Kaolinite is the most abundant clay mineral species in the well, with amount ranging from 0.1 % to 31.28 % (mean, 11.84 %) in the well (Table 2). The relative amount of kaolinite increase gradually with depth. Illite/muscovite occurs as a relatively minor clay mineral component in all the samples investigated with abundance varying between 0 % - 3.94 %. Illite/muscovite abundances range between 0 to 1.41% (mean, 0.47 %). The variation observed in the Illite/muscovite abundance in the well may reflect difference in depositional environments. The percentage of chlorite in the well is relatively small. The percentage of chlorite varies between 0 % to 0.43 % (mean, 0.115 %). The percentage of chlorite is nearly constant with depth. The percentage of sepiolite in the well tends to increase with depth. The percentage varies between 0.25 % to 1.57 % (mean, 0.63 %).

3.2.2. *Non clay minerals*

Quartz is the predominant non-clay mineral in the mudrock (Figs. 3-5). Its abundance ranges between 46.53 % to 98.6 % (mean, 77.13 %). The percentage of feldspar in the rock is generally low. The percentage of microcline is generally more than that of plagioclase feldspar. Microcline generally increases with depth with percentage that varies between 0 % to 8.11 % (mean 3.32 %). The plagioclase varies between 0 % to 3.65 % (mean, 0.96 %). Other non-clay minerals in the well include siderite, dolomite, calcite, pyrite, anatase, jarosite, barite and fluorite occur in percentage usually less than 5 % for each mineral.

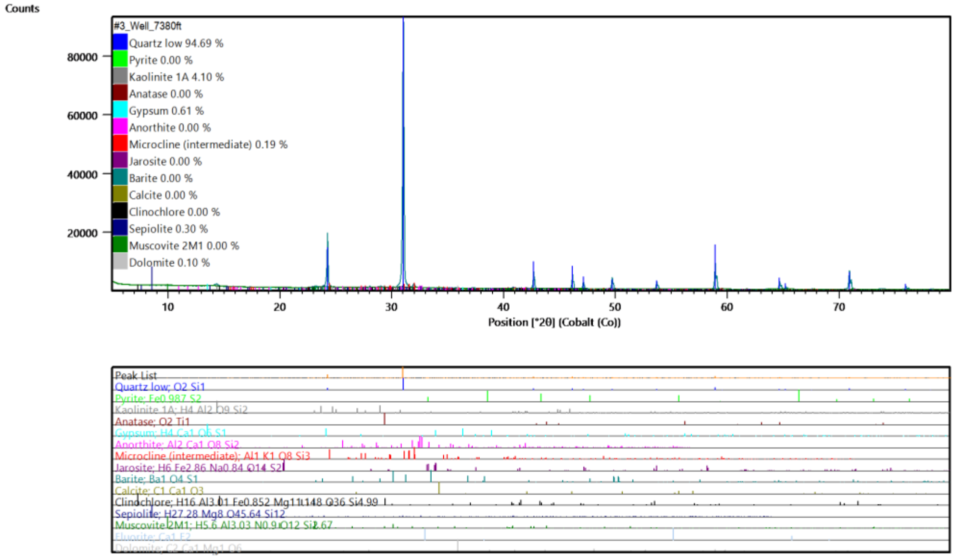

Fig. 3. XRD pattern for #3 Well at 7380 ft.

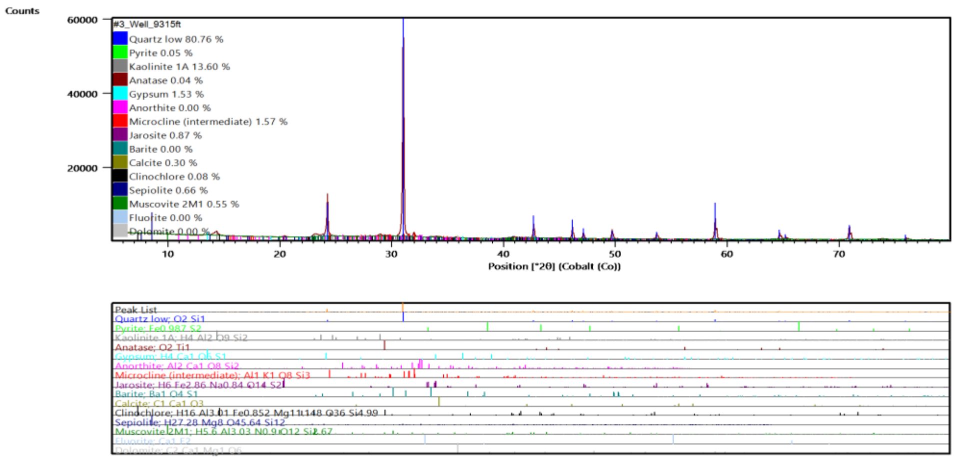

Fig. 4: XRD pattern for #3 Well at 9645 ft.

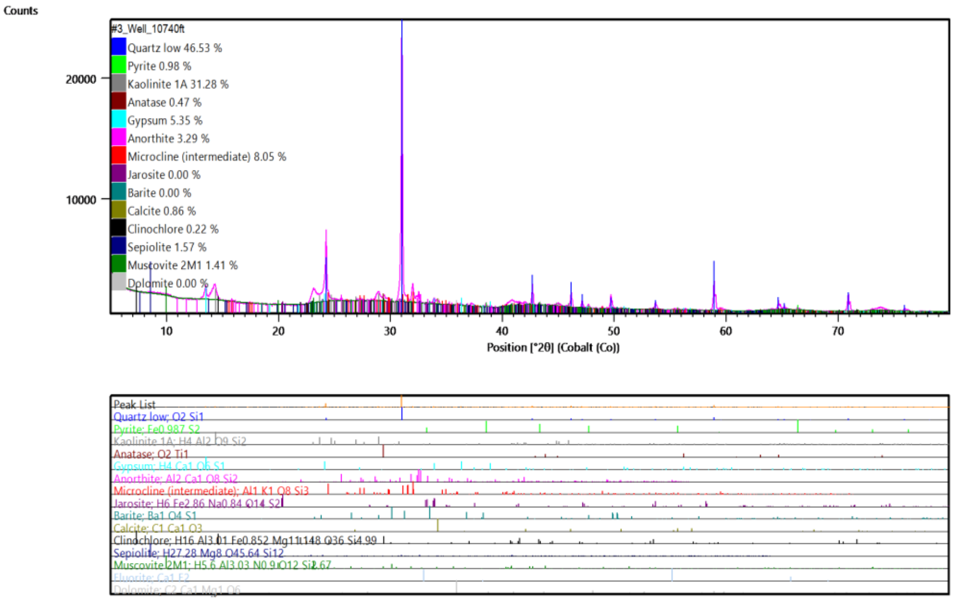

Fig. 5. XRD Diffractogram for #3 Well at 10740 ft.

Table 2. Bulk XRD Analysis for #3 Well.

	Clays				Carbonates			Other minerals							
Depth (ft.)	Kao.	Ill.	Chl.	Sep.	Cal.	Dol.	Qtz.	Pyr.	Anat.	Gyp.	Pla.	Mic.	Jar.	Ba.	Flu.
6600	0.1	0	0	0.25	0	0	98.6	0.06	0	0.76	0	0	0.23	0	0
7380	4.1	0	0	0.3	0	0.1	94.69	0	0	0.61	0	0.19	0	0	0
8685	4.78	0.04	0	0.46	0.69	0	91.71	0	0	1.18	0	0	1.14	0	0
9315	13.6	0.55	0.08	0.66	0.3	0	80.76	0.05	0.04	1.53	0	1.57	0.87	0	0
9645	9.69	0.28	0.28	0.57	0.09	7.23	76.22	0.63	0	1.67	0	3.34	0	0	0
10320	14.88	0.78	0.34	0.32	6.61	1.6	61.41	0.41	0.2	1.69	3.65	8.11	0	0	0
10740	31.28	1.41	0.22	1.57	0.86	0	46.53	0.98	0.47	5.35	3.29	8.05	0	0	0
11070	16.36	0.72	0	0.92	2.27	0	67.17	0	0.16	3.69	0.74	5.32	2.63	0	0

3.3. Prediction of reservoir quality

Reservoir characteristics prediction has becomes a key challenge for exploration and development of hydrocarbon prospects in oil fields. The study shows the presence of kaolinite, illite/muscovite, chlorite and sepiolite. These clay minerals have different effects in controlling the reservoir characteristics, wettability and mobility of oil. The occurrence of kaolinite in the sandstone increases the water wetness of the reservoir rock [20]. The migrated kaolinite reduces the permeability of reservoir rocks by filling some of the available pore space. Hence, due to the high percentage of kaolinite in the well, there is possibility that there could be a reduction in the permeability of the reservoir as a result of the pore filing kaolinite. Illite which is a pore bridging and non-swelling clay tend to come off from the rock surface and move with the injection water when the salt concentration of the injection water is low [21]. Since illite has filamentous habit, there is possibility that it could bridge the pore space which could reduce the porosity and permeability. The migrating particle (illite) may get deposited on the wall of the pore throats causing a reduction of reservoir permeability. It can be seen that loss of permeability of a reservoir can be attributed to the occurrence of clay minerals. Since illite occurs as minor clay mineral component in the well, the possibility that there will be loss of reservoir permeability in the well will be negligible. The percentage of chlorite in the well is nearly constant with depth. The low percentage of chlorite in the well shows that the pore lining characteristics of chlorite may not affect the reservoir quality.

3.4. Implication for hydrocarbon exploration

Lithofacies analysis has been demonstrated to be a hierarchical stratigraphic technique that can be applied in characterizing potential source and reservoir rock in any well [4]. The source and reservoir rocks are within the Agbada formation [14,17]. The zones of the potential source rock are within the shale. The source rock zones are between homogenetic zones 6 to zone 14, while the reservoir rocks are within the sandy shale to sandstone zones. The reservoir rock zones are between heterogenic zones 18 to zone 28.

3.5. Environment of deposition

Sedimentary parameters used to identify environment of deposition for are similar to those defined by [18]. Considering the textural properties, mineralogical composition, fossil content, shale to sand ratio, homogeneity and heterogeneity of the lithofacies units for the well, the depositional environment range from paralic to transitional and continental environments.

4. Conclusion

The lithofacies analysis identified 5 lithofacies types of mainly sandstone, clayey sandstone, shaly sandstone, sandy shale and shale, and 53 lithofacies zones. The minerals identified in the well are quartz, iron oxide, pyrite, carbonate, mica and clay minerals. Kaolinite has high percentage from the X-ray diffraction analysis which is likely to block the spore space of the reservoir rocks due its pore filing nature. The percentage of illite is minimal; therefore the pore bridging characteristics of illite will not have significant effect on the reservoir quality. The percentage of the pore lining chlorite from the clay mineralogy is small. The ability of chlorite to reduce the porosity and permeability of the reservoir rock will be minimal. Therefore, due to the high percentage of kaolinite in the well (0.1 % to 31.28 %), it could be concluded that pore filing kaolinite may have more effect on the reservoir quality than the pore bridging illite and pore lining chlorite.

In conclusion, by considering the textural properties, mineralogical composition, fossil content, homogeneity and heterogeneity of the lithofacies units, the clay and non-clay minerals for the well, it can be concluded that the well has fair reservoir quality that will not significantly favor hydrocarbon exploration.

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