International Journal of Basic Science and Technology ISSN 2488-8648
August 2018, Volume 4, Number 3, Pages 86 - 98 http://www.ijbst.com/

Petrophysical Analysis of Reservoirs at Etsako Field, Niger Delta Basin Nigeria, Using Open-Hole Geophysical Logs

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Article Information

Article # 1014
Received: 18^{th} Oct., 2018
Revision 12^{th} Dec., 2018
Acceptance: 17th Dec., 2018
Published: 24^{th} Dec., 2018

Key Words
Hydrocarbon saturation,
Petrophysical properties,
Reservoirs,
Water saturation

Abstract

This research focused on petrophysical aspects of reservoirs within Etsako-Field, Niger Delta Basin, Nigeria using open hole geophysical well logs. The study area is about 1.22km^2 and lies approximately within latitudes $5^o\ 4^1\ 8^{11}$N and $5^0\ 6^0\ 5^{11}$ N and longitudes $6^0\ 4^1 6^{11}$E and $6^0\ 7^1 6^{11}$ E. The study was conducted to update petrophysical estimates of Etsako-Field using techniques of sequence stratigraphy. Petrophysical evaluation is commonly conducted using effective porosity estimated from equation that is not time sensitive. Hydrocarbon saturation values estimated using such equations will be erroneous. Porosity estimates in the reservoirs ranges from 0.168 to 0.2466. Estimated hydrocarbon saturation ranges from 0.534 to 0.620 in the hydrocarbon reservoirs. Drilling should be concentrated on infill wells between ET-6 and ET-3, ET-3 and ET-1 which will result to increase volume of hydrocarbon in reservoir sand-I. Infill wells drilled between well ET-6 and ET-3, ET-3 and ET-1 will also increase productivity from reservoir sand-F2, Sand-B and Sand-M. Drilling should be avoided between ET-2 and ET-5; they will produce only water. Further exploration should focus on the Lowstand Systems (LST) Tracts because most of the producible hydrocarbon accumulations are found within the LST in the field.

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Introduction

The Niger Delta basin is one of the economically important basins because of its enormous petroleum reserves. Petroleum accumulations in the subsurface are indirectly explored by using predominantly the techniques of reflection seismology. These techniques can only delineate subsurface zones with high potential for petroleum accumulation. The reservoirs within which the accumulations are trapped can only be detected and delineated by conducting mud logging and geophysical logging of the wells (Ditzhuijzen, 1994, Raijers, 2011, Kadhim *et al.*, 2015).
It has being found that petrophysical logs interpretations used for the characterization of reservoir sands are very useful and important tools for selecting and implementing operationally sound supplementary recovery schemes as reported in the research work of (Ekine and Iyabe, 2009, 2015, Qasim, 2010, El-Khadragy *et al.*, 2016., Asubiojo and Okunuwadje).

Sequence and petrophysical analysis of a field with a few wells can reveal opportunities for drilling additional successful wells. This will optimize the recovery of petroleum production from the subsurface. The sequence analysis entails establishing vertical and lateral relationships of the penetrated rock strata. The state of the art technique for achieving this is anchored on sequence and Para sequence concepts as reported by (Van Wagoner *et al.*, 1990, Jahani *et al.*, 2009, Behjet *et al.*, 2014., Amel, 2015, Yuanzhong *et al.*, 2015).
Report on the petrophysical evaluation of the reservoir sands, (Omoboriowo *et al.*, 2012, Rotimi *et al.*, 2013, Alao *et al.*, 2013, Akintola *et al.*, 2015 and Mode *et al.*, 2015) had independently investigated the Niger Delta Basin offshore deposit and noted that petrophysical properties of the reservoirs sand of the formation are high enough to permit to hydrocarbon production.

ISSN 2488-8648
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It was noted in Akintola *et al.*, 2015 research work that the sand of the Niger Delta is deposited in different environments consisting of distributary, channels, mouth Barrier Island and tidal channels and were deposited across normal growth faults and additional structures.

The objective of the study is to identify the depositional environment, estimate and compare the porosity, permeability and water saturation distribution within the field, identify specific reservoir sand bodies, and predict the reservoir system quality and performance.

Location and Geology of the Study Area

The field lies between Latitudes $5^\circ\ 4^1\ 8^{11}$ N and 5° 6′ 5″ N and Longitudes 6° 4′ 6″ E and 6° 7′ 6″ E and covers an area of $1.22km^2$. The Niger Delta basin is located within the perioceanic section of the Abakaliki-Benue suture Zone of the much larger southern Nigerian basin. On the west, it is separated from the Dahomey (or Benin) basin by the Okitipupa basement high, and on the east it is bounded by the Cameroun volcanic line. Its northern margin transects several older (Cretaceous) tectonic elements—the Anambra basin, Abakaliki uplift, Afikpo syncline, and Calabar Flank (Figure 2.0). The evolution of the delta is controlled by pre- and synsedimentary tectonics as described by Stacher (1994)

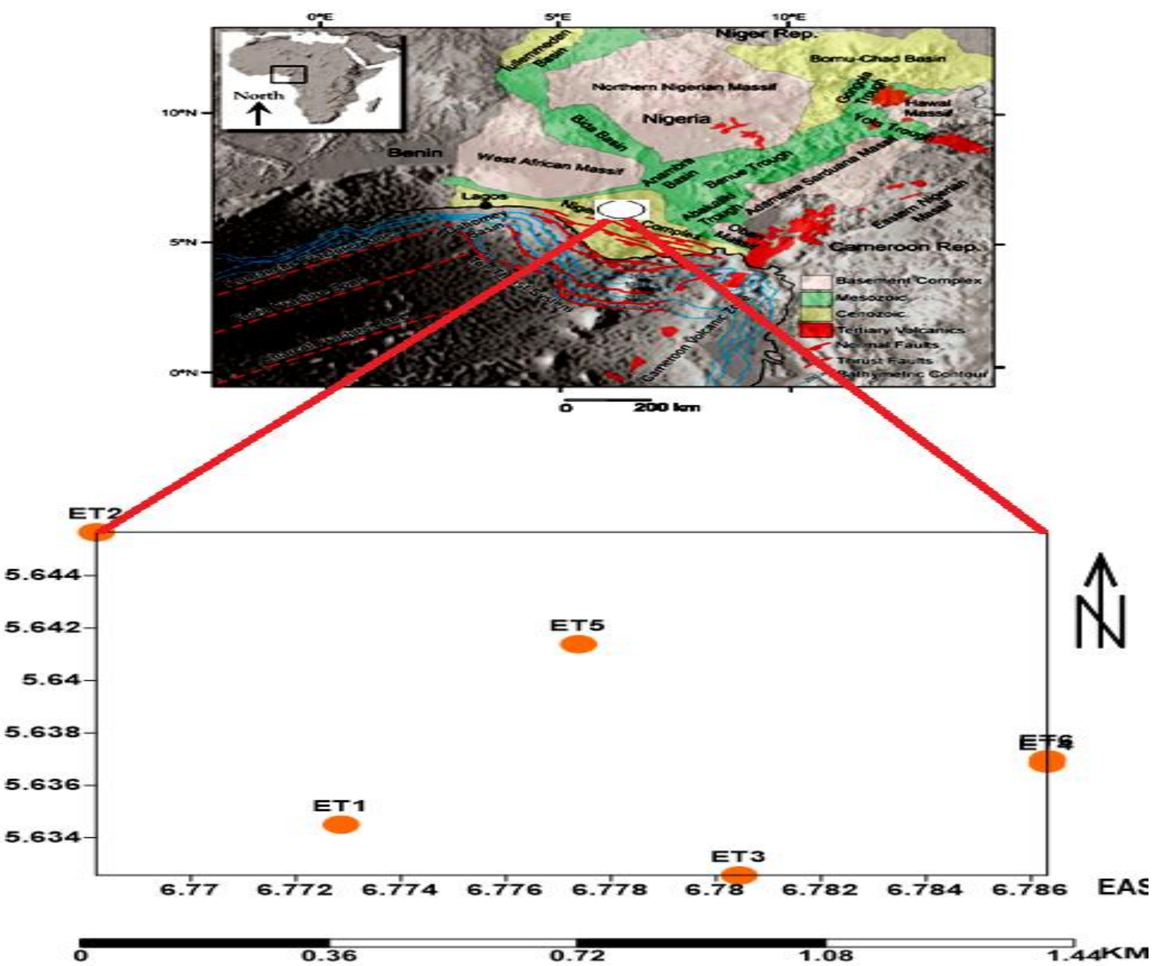

Figure 1.1: Location map of the study area showing the six wells (Modified after Unuevho, 2016)

Materials and Methods

Petrophysical Evaluation of the Reservoirs (Shale Volume (V_{sh}) Computation)

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The first step was to determine the gamma ray index (I_{GR}) using the equation (1.1), then Shale Volume (V_{sh}) is calculated using the Steiber formula (1.2) which is particularly for tertiary rocks.

Where GR_{log} is gamma ray reading from the log (formation), GR_{min} is the minimum gamma ray reading (clean sand), GRmax is the maximum gamma ray reading (shale), $I_{GR=\text{ Gamma ray index}}$

The Bulk Volume of Water: The Bulk Volume of water was calculated using equation 1.3.

$$BVW = \Phi S_W \quad (1.3)$$

where: BVW = bulk volume water, Φ=porosity and $S_{W=}$ water saturation.

Porosity (Φ) Calculation: Porosity was calculated as the pore volume of the rock divided by its bulk volume

$$\phi = \frac{V_P}{V_B} \quad (1.4)$$

Where Φ = porosity; V_p = pore volume; and V_B = bulk volume.

$$I_{GR} = \frac{GR_{log}-GR_{min}}{GR_{max}-GR_{min}} \quad (1.1)$$

$$VSHsteiber = \frac{IGR}{3-2IGR} \quad (1.2)$$

Water Saturation (S_w) estimation. The water saturation was calculated using Indonesian Equation

$$S_w^{\,n} = 1/\{\sqrt{R_t}(V_{clay}^{(1-Vcl/2)}/\sqrt{R_{clay}} + \phi^{m/2}/\sqrt{aR_w})\} \quad 1.5$$

where: Rclay – Resistivity of Clay/Shale in formation,

S_w = Water Saturation, Rt= true resistivity of uninvaded, deep formation (Ωm)

n = saturation exponent m= cementation factor

R_w = resistivity of the water zone,

All the equations are embedded in the Geographix Discovery TM 5000 software employed in the study wells.

Results and Discussion

Petrophysical and Reservoir Sands Analysis: Four major reservoirs with hydrocarbons were delineated across Etsako Field (Figure 2, 3, 4, 5, 6, 7). These reservoirs are: Sand-B, Sand-F2, Sand-I and Sand-M. They occur in ET-6, ET-1, and ET-3

ET-1

Two reservoirs sands-I and sand-M occur in this well. They have average thickness 198 ft (60.35 m) in reservoir sand-I to 175 ft (53.34 m) in reservoir sand-M (Table 1a and 2a). Reservoir Sand- I occur at depth between 6527 ft (1989.42 m) to 6725 ft (2049.78 m) while sand-M occur at a depth of 8355 ft (2546.604 m) to 8553 (2606.95 m). Sand-I occur in the low stand systems tracts (LST) in parasequence 10. Sand-M occurs in the LST in parasequence 14.

The average volume of shale (Vsh) in reservoir sand I is 0.05v/v and 0v/v in sand M (Table 1c and 2b). This suggest the reservoirs sand-I and sand-M with these low volume of shale are hydrocarbon bearing. The average resistivity value in reservoir sand I is 183.85 ohm-meter and for reservoir sand-M is 174.85 ohm-meter (Table 1a). These high resistivity obtained confirm the presence of hydrocarbon in these reservoirs. The water saturation (Sw) in sand-I and sand-M are 0.473 and 0.38 respectively. The low water saturation is an indication that the hydrocarbon saturations are higher. The average density porosities in the two reservoirs are: 0.185 in sand-I and 0.168 in sand-M (Table 1a).

Table 1a: Petrophysical Properties of Sand-I ET-1

RESERVOIRS (ft)	TOP (ft)	BASE (ft)	Thickness	Vsh	NetRes	Sw	Phipay	Netpay
I	6527	6725	198	0.05	183.85	0.473	0.185	21.5
M	8363	8538	175	0.00	174.85	0.380	0.168	104.5

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ISSN 2488-8648
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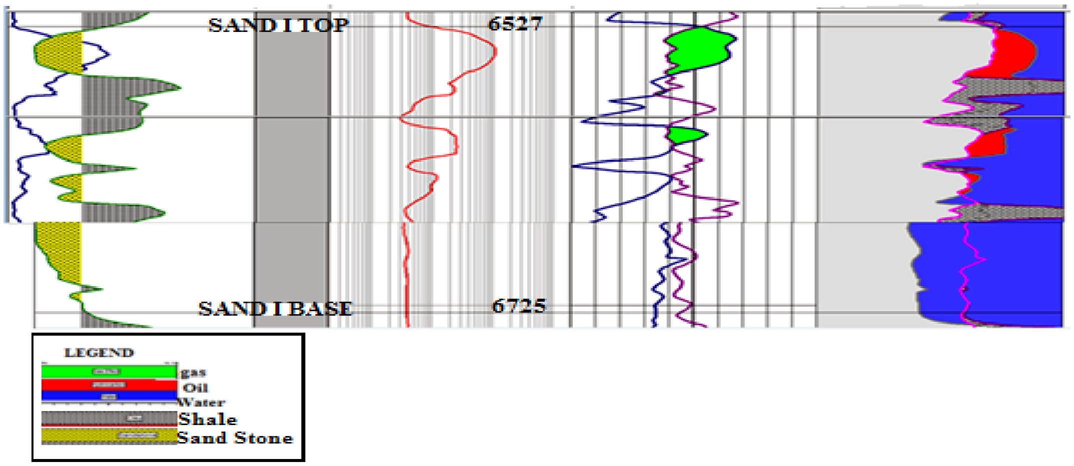

Figure 2: Reservoir sand-I ET-1

Table 1b: Petrophysical Properties of Sand-I ET-1

GrossInt MD	GrossInt TVD	GrossRes MD	GrossRes TVD	NetRes MD	NetRes TVD	Netpay MD	Netpay TVD
195.85	195.85	183.85	183.85	183.85	183.85	21.50	21.50

Table 1c: Petrophysical Properties of Sand-1 ET-1

N/Gpay MD	N/Gpay TVD	N/Gres MD	N/Gres TVD	Phipay MD	Phipay TVD	SWpay MD	Swpay TVD	Vshpay MD	Vshpay TVD
0.11	0.11	0.939	0.939	0.185	0.185	0.473	0.473	0.051	0.051

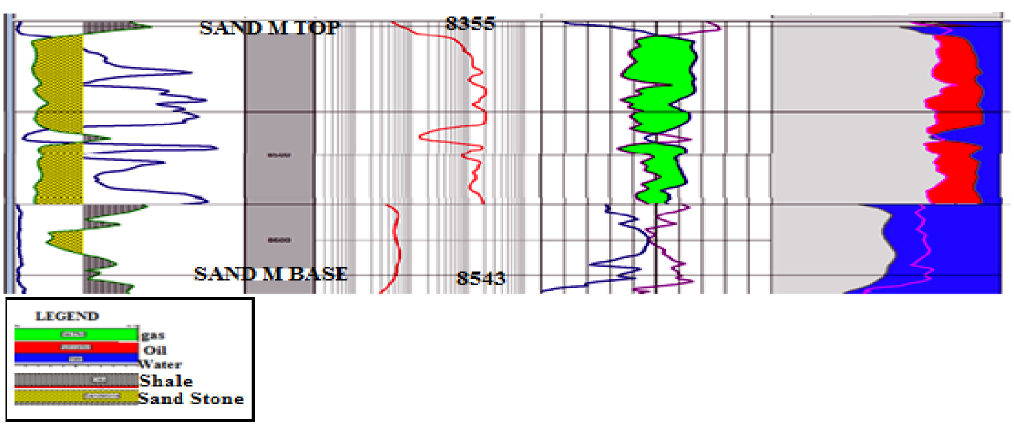

Figure 3: Reservoir sand-M ET-1

Table 2a Petrophysical Properties of Sand-M ET-1

GrossInt MD	GrossInt TVD	GrossRes MD	GrossRes TVD	NetRes MD	NetRes TVD	Netpay MD	Netpay TVD
175.02	175.02	175.02	175.02	174.85	174.85	104.5	104.5

Table 2b: Petrophysical Properties of Sand-M ET-1

N/Gpay MD	N/Gpay TVD	N/Gres MD	N/Gres TVD	Phipay MD	Phipay TVD	SWpay MD	Swpay TVD	Vshpay MD	Vshpay TVD
0.597	0.597	0.999	0.999	0.168	0.168	0.38	0.38	0	0

ET-3

Two reservoirs sand-I and sand-M occur in ET-3. The reservoirs range in thickness 90 ft (27.432 m) in sand-I to 131ft (39.93 m) in sand-M. Reservoir Sand-I occur at a depth of 6512 ft (1984.9 m) and 6718 ft (2047.65 m) while sand-M occur at depth 8390 ft (2557.27 m) to 8572 ft 2612.75 m). Sand-I occur in the LST in parasequence 10 while Sand-M occurs in the LST in parasequence 14. The average volume of shale (Vsh) in sand-I, ET-3 is 0.028v/v and 0v/v in sand-M (table 3a). The average resistivity value in reservoir sand-I ET-3 is 82.94 and for sand-M is 126.69 (table 3a). The water saturation (Sw) in sand-I and sand-M are 0.505 and 0.572 respectively. The average density porosities in the two reservoirs are: 0.215 and 0.192.

Table 3a: Petrophysical Properties of Sand-I, Sand-M ET-3

RESERVOIRS	TOP(ft)	BASE(ft)	THICKNESS(ft)	Vsh	NetRes	Sw	Phipay	Netpay
I	6512	6602	90	0.028	82.94	0.505	0.215	25
M	8392	8523	131	0.00	126.69	0.572	0.192	6

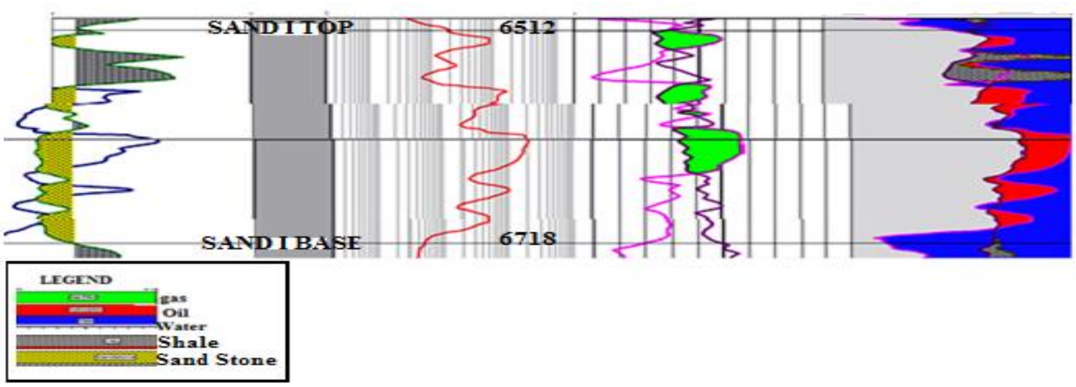

Figure 4: Reservoir sand-I ET-3

Table 3b: Petrophysical Properties of Sand-I ET-3

GrossInt MD	GrossInt TVD	GrossRes MD	GrossRes TVD	NetRes MD	NetRes TVD	Netpay MD	Netpay TVD
88.94	88.94	82.94	82.94	82.94	82.94	25	25

Table 3c: Petrophysical Properties of Sand-I ET-3

N/Gpay	N/Gpay	N/Gres	N/Gres	Phipay	Phipay	SWpay	Swpay	Vshpay	Vshpay

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MD	TVD	MD	TVD	MD	TVD	MD	TVD	MD	TVD
0.281	0.281	0.933	0.933	0.215	0.215	0.505	0.505	0.028	0.028

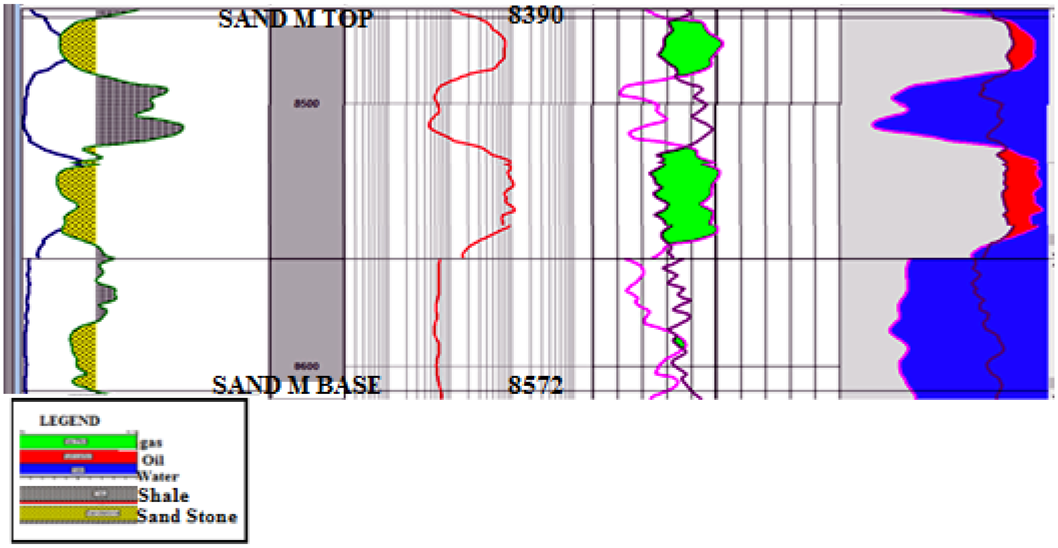

Figure 5: Reservoir sand-M ET-3

Table 4a: Petrophysical Properties of Sand-M, ET-3

GrossInt MD	GrossInt TVD	GrossRes MD	GrossRes TVD	NetRes MD	NetRes TVD	Netpay MD	Netpay TVD
126.69	126.69	126.69	126.69	126.69	126.69	6	6

Table 4b: Petrophysical Properties of Sand-M ET-3

N/Gpay MD	N/Gpay TVD	N/Gres MD	N/Gres TVD	Phipay MD	Phipay TVD	SWpay MD	Swpay TVD	Vshpay MD	Vshpay TVD
0.047	0.047	1	1	0.192	0.192	0.572	0.572	0	0

ET-6

Two reservoirs, sand-B and sand-F2 occur in this well. The reservoirs have thickness 22 ft (6.706 m) for sand-B and 45 ft (13.716 m) sand-F2. Sand-B occur at a depth of 4892 ft (1491.08 m) to 4928 ft (1502.05 m) while sand-F2 occur at depth of 5901ft (1798.62 m) to 5953 ft (1814.47 m). Sand-B occur in the LST in parasequence 3 while sand-F2 occur in the LST in parasequence 8. The average volume of shale (Vsh) in sand-B ET-6 is 0.015 v/v and 0.023 v/v for sand-F2 (4.12A). The average resistivity value in reservoir sand-B ET-6 is 25.9 and for sand-F2 is 44.34. The water saturation (Sw) in sand-B and sand-F2 are 0.485 and 0.466 respectively. The average density porosity in the two reservoirs are: 0.235 and 0.2466 (Table 5 and figure 6).

Table 5a: Petrophysical Properties of ET-6

RESERVOIRS (ft)	TOP (ft)	BASE (ft)	THICKNESS	Vsh	NetRes	Sw	Phipay	Netpay
B	4975	4997	22	0.015	25.9	0.485	0.235	14.5
F2	5908	5953	45	0.023	44.34	0.466	0.2466	23.5

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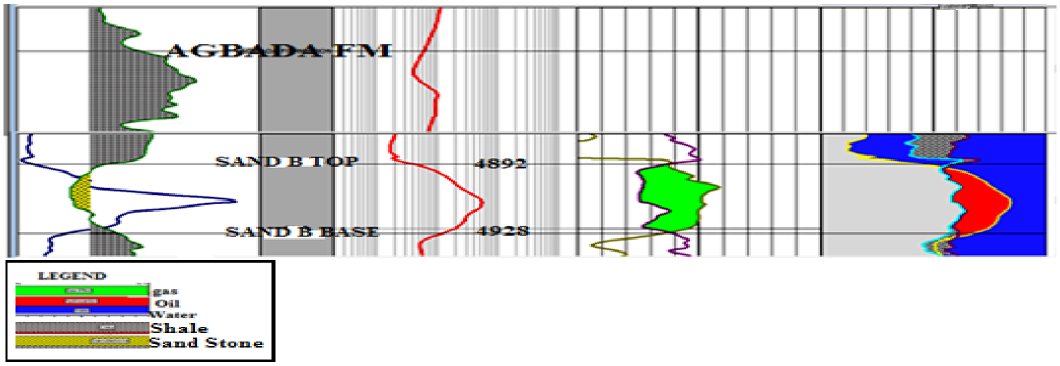

Figure 6: Reservoir sand B ET-6

Table 5b: Petrophysical Properties of Sand-B ET-6

GrossInt MD	GrossInt TVD	GrossRes MD	GrossRes TVD	NetRes MD	NetRes TVD	Netpay MD	Netpay TVD
25.9	25.9	25.9	25.9	25.9	25.9	14.5	14.5

Table 5c: Petrophysical Properties of Sand-B ET-6

N/Gpay MD	N/Gpay TVD	N/Gres MD	N/Gres TVD	Phipay MD	Phipay TVD	SWpay MD	Swpay TVD	Vshpay MD	Vshpay TVD
0.56	0.56	1	1	0.235	0.235	0.485	0.485	0.015	0.015

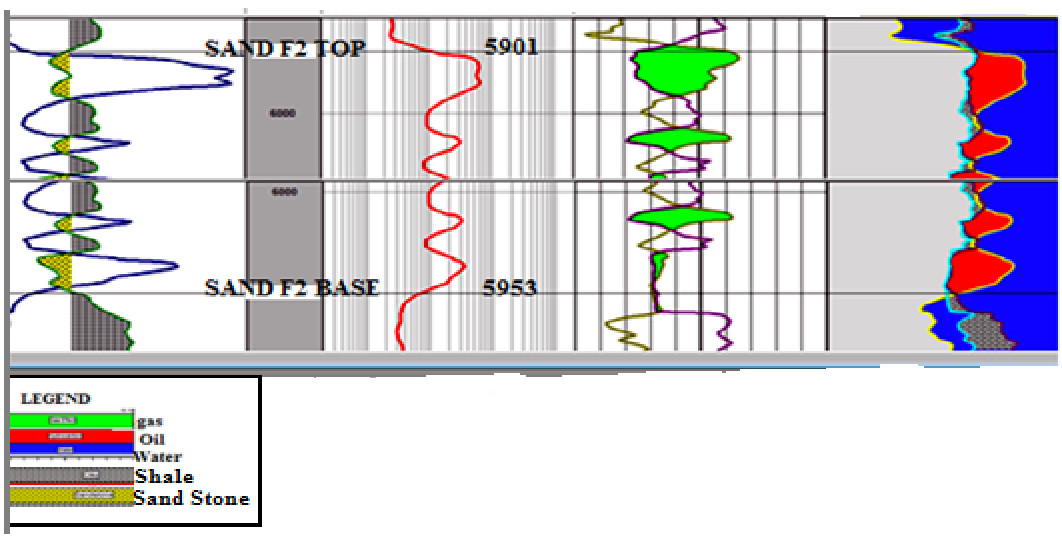

Figure 7: Reservoir sand-F2 ET-6

Table 6a: Petrophysical Properties of Sand-F2 Et-6

GrossInt MD	GrossInt TVD	GrossRes MD	GrossRes TVD	NetRes MD	NetRes TVD	Netpay MD	Netpay TVD
44.34	44.34	44.34	44.34	44.34	44.34	23.5	23.5

Table 6b: Petrophysical Properties of Sand-F2 Et-6

N/Gpay MD	N/GpaY TVD	N/Gres MD	N/Gres TVD	Phipay MD	Phipay TVD	SWpay MD	Swpay TVD	Vshpay MD	Vshpay TVD
0.53	0.53	1	1	0.2466	0.2466	0.466	0.466	0.023	0.023

Sand Tops

The sand top for ET-1 to ET-6 are given in figure 8, 9, 10 and 11 accordingly.

Sand-B Top

The contour interval across sand B is 10 ft (3.048 m). The elevations of the wells increased towards the west across ET-1 and ET-2. The elevation also increases from ET-5 towards the East. However, there is a decreased in elevation towards the North-East along ET-3. The topography across sand-B is generally gentle but becomes steeper towards ET-6 (Figure 8).

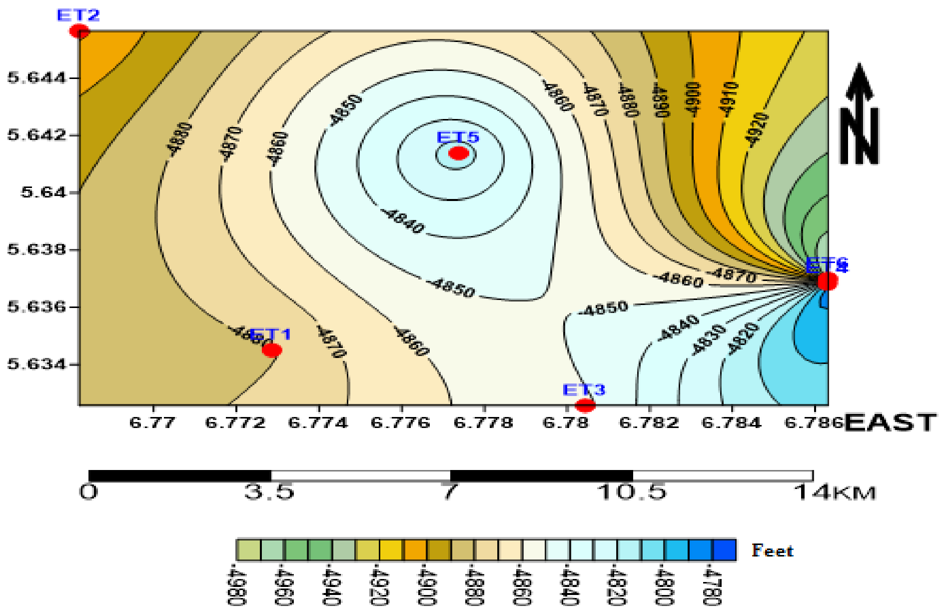

Figure 8: Sand-B Top

Sand F-2 Top

The contour interval across sand-F2 is 10ft (3.048 m). There is an increased in elevation from ET-3 to ET-1. The topography increases also from ET-5 towards the east. The topography however, decreases towards the North-East. Generally, there was increased elevation from East-to West across the sand (Figure 9).

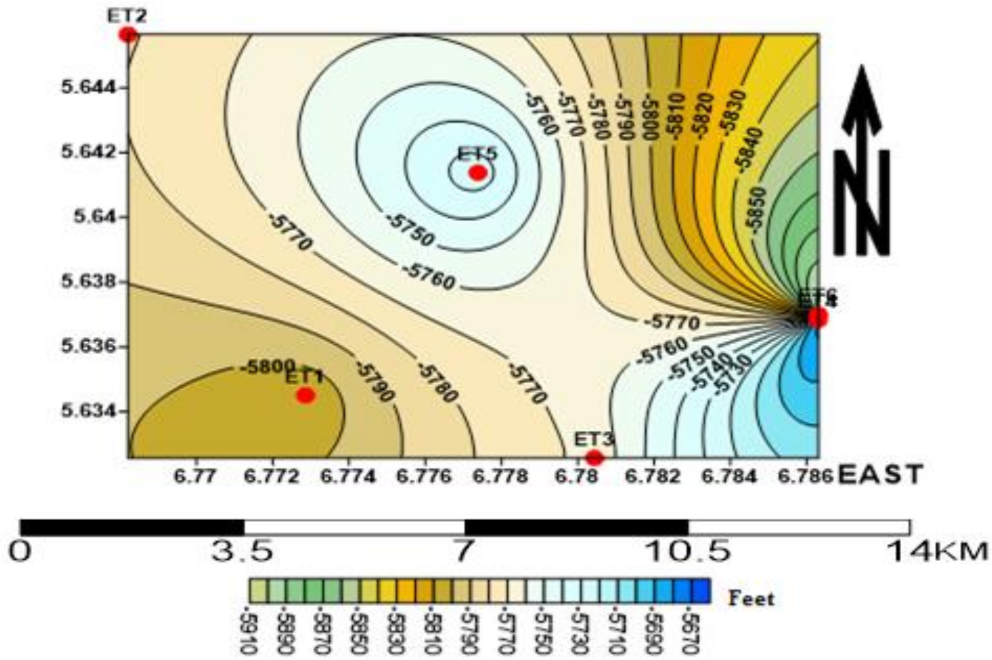

Figure 9: Sand-F2 Top

Sand-I Top: The contour interval across sand-I is 20 ft (6.096 m). The slope is generally gentle across sand-I. It increases from the South-West towards the South-East. It however steeper towards ET-6 (Figure 10).

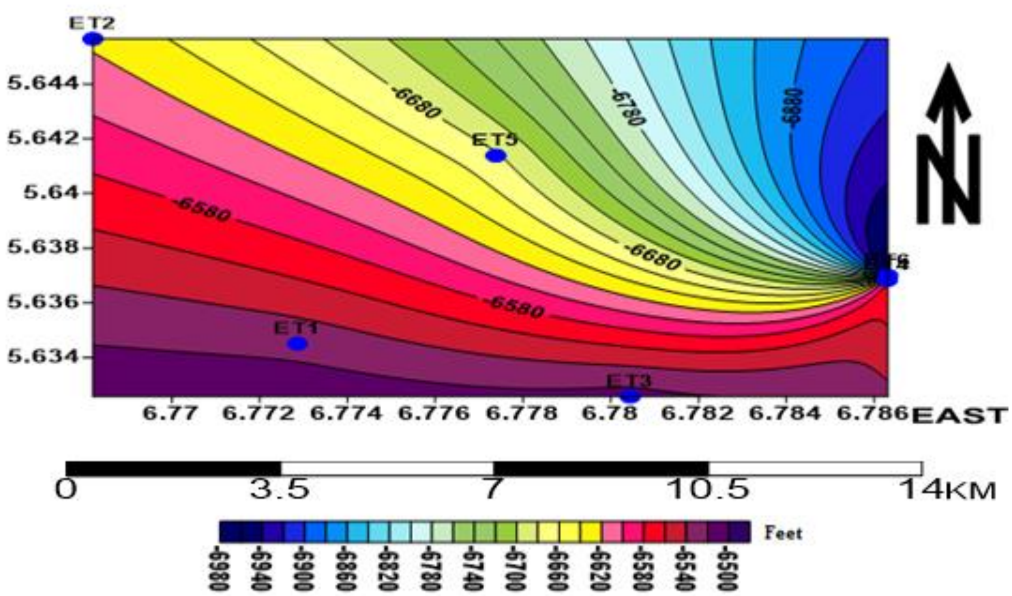

Figure 10: Sand-I Top

Sand-M: The contour interval across sand-I is 10 ft (3.048 m). There is an increased in elevation from South to the North in ET-1. In ET-3, there is a decreased in elevation from North to the South across sand-M (Figure 11).

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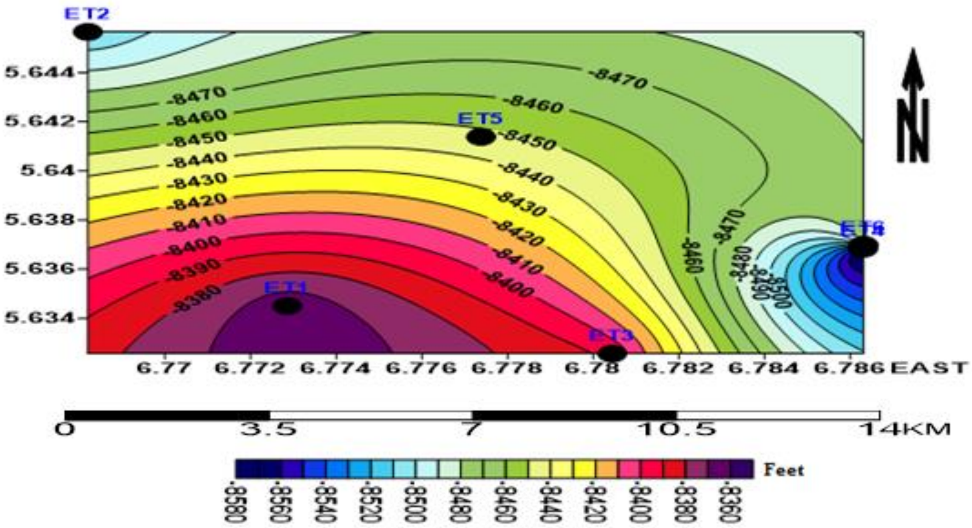

Figure 11: Sand-M Top

Isopach Maps: The isopach (thickness map) for the six wells are given in figure 12, 13 and 14 respectively.

Sand-B Thickness

The depositional pattern of the study wells as related to the overlying and underlying strata in sand-B is 1ft (0.3048 m) interval thickness map (Figure 12). The thickness of ET-1 ranges from 27-30 ft (8.330m-9.144 m) and increases towards the eastern direction. ET-2 ranges in thickness from 33-31 ft (10.06 m-9.45 m). It decreases towards the southern and eastern direction of the field. ET-3 ranges in thickness from 34-31 ft (10.36 m-9.45 m); it increases towards the south and decreases towards the northern and eastern part of the field. ET-5 ranges in thickness from 34-31 ft (10.36 m-9.45 m); it decreases towards the western, eastern and northern direction. ET-6 ranges in thickness from 22.5-29 ft (6.858 m-8.840 m). ET-6 is productive in sand-B.

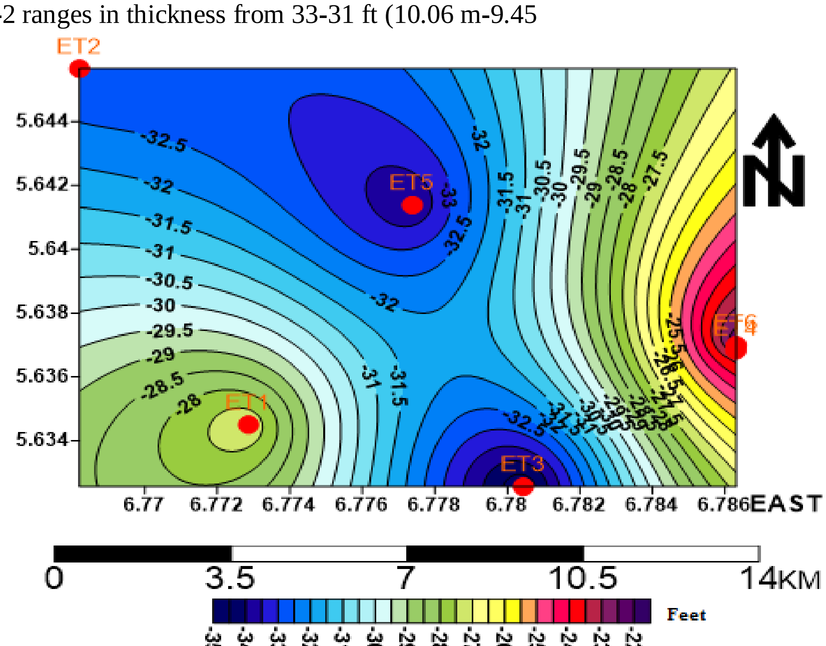

Figure 12: Sand-B Thickness across Etsako Field

Sand-F2 Thickness: The isopach map in sand-F2 (see figure 13) has a contour interval of 4feet (1.230 m). ET-1 ranges in thickness from 38-30 ft (11.58 m-9.144 m). It decreases towards the eastern direction and increases towards the west. ET-2 ranges in thickness from 70 ft-42 ft (21.34 m-12.80 m). The

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thickness decreases towards the northern direction.ET-3 ranges in thickness from 28-30 ft (8.534 m-9.144 m). It increases in the eastern and western directions. ET-5 ranges in thickness from 24-30 ft (7.32 m-9.144 m); increases in the eastern and western direction. ET-6 ranges in thickness from 44 ft—34 ft (13.41 m-10.36 m). It decreases towards the western direction. ET-6 is productive in sand F-2.

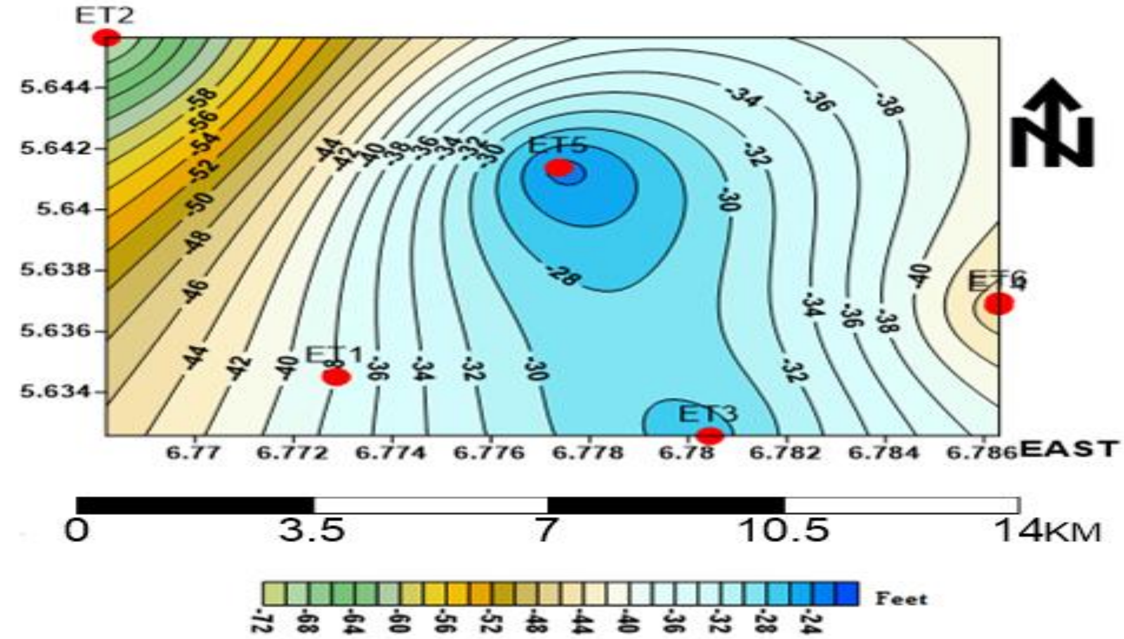

Figure 13: Sand-F2 Thickness

Sand-I Thickness: The isopach map in sand-I (figure 14) has a contour interval of 20 ft (6.096 m). ET-1 has thickness ranging from 20-160 ft (6.09-48.77 m); it increases in the eastern and northern direction. ET-2 ranges in thickness between 220-210 ft (67.06 m-48.77 m). ET-3 ranges in thickness from 100 ft-160 ft (30.48 m-48.77 m); the thickness increases towards the eastern and western directions. ET-6 ranges in thickness from 70-130 ft (21`.34 m-39.62 m). The thickness increases towards the western direction. ET-1 and ET-3 are productive in sand-I.

Sand-M Thickness: The isopach map of sand-M has a contour interval of 5 ft (1.524 m). ET-1 has a thickness ranging from 145 - 165 ft (44.196 m-50.292 m); it increases towards the eastern direction. ET-2 range in thickness from 70-95 ft; increases towards the southern direction. ET-3 has a thickness ranging from 140 - 120 ft (42.672 m-36.576 m). The thickness of ET-3 increases towards northern direction. Sand-M is virtually absent in ET-5. ET-6 ranges in thickness from 75-120 ft (22.86 m -36.576 m). ET-6 increases towards the northern direction. ET-1 and ET-3 has hydrocarbon in this sand.

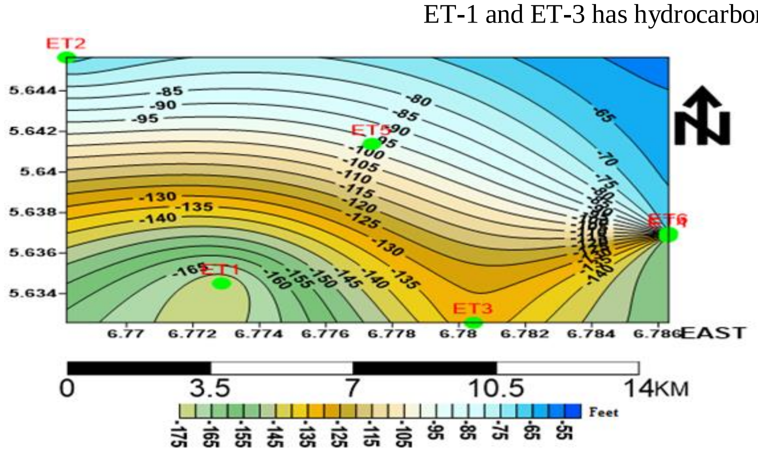

Figure 15: Sand-M Thickness

Conclusions

The study revealed that the wells penetrated only Benin and Agbada Formation. The top of the Agbada Formation which demarcates the formations was defined in the study area by a minimum of 500 ft of shale with resistivity value of 3-5 Ωm. The sand component within the shale interval is less than 40 percent. The sand percentages were found to range from 80 percent to less than 20 percent, and represent depositional environments that range from continental to marine.

Identified hydrocarbon reservoirs are Sand-I, Sand-M, Sand-B and Sand-F2. Estimated porosity in these reservoirs ranges from 0.168 to 0.247. Estimated hydrocarbon saturation ranges from 0.534 to 0.620 in the hydrocarbon reservoirs.

Drilling infill wells between ET-6 and ET-3, ET-3 and ET-1 will increase volume of hydrocarbon in reservoir sand-B. Infill wells drilled between well ET-6 and ET-3, ET-3 and ET-1 will also increase productivity from reservoir sand-F2, Sand-I and Sand-M. Drilling should be avoided between ET-2 and ET-5 because these wells are located below the hydrocarbon-water contact.

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