Subsurface Mapping and Reservoir Evaluation of West Waha and Worsham-Bayer Field Area of Southeastern Delaware Basin, West Texas.

Kehinde A. Haruna, M.Sc. [1*]; **Olusola J. Ojo, Ph.D.**[1];
and Wasiu Odufisan, Ph.D.[2]

[1]University of Ilorin, Ilorin, Nigeria.
[2]ExxonMobil Producing Unlimited.

E-mail: solafoluk@yahoo.com*

ABSTRACT

This study aims at quantifying the hydrocarbon in place and estimation of hydrocarbon reserves in the West Waha and Worsham-Bayer Field, Southeastern Delaware Basin, West Texas. The data set used for this research includes approximately 20 mile^2 (approx. 52km^2) 3-D seismic data, a set of 10 digitized well logs and production history. Well correlation, seismic interpretation, petrophysics, volumetrics, reservoir decline curve analysis, and reserve estimate were carried out using Petrel and Geographix software. Four reservoirs were identified and Ellenburger has the highest thickness of all the reservoirs, with average netpay of 245ft, 0.5NTG (net to gross) and 25% effective porosity. Fusselman has an average netpay of 132ft, 0.4NTG and 26% effective porosity while the Thirtyone reservoir has an average netpay of 189ft, 0.25NTG and 23% effective porosity. The Undifferentiated Mississipian Limestone has an average netpay of 82ft, 0.18NTG and 25% effective porosity. The average water saturation (Sw) for the reservoirs is 0.2.

Seismic to well tie was carried out using the checkshot for well 37 and hydrocarbon bearing zones were delineated. Eight faults were identified, F1, F2 and F3 are the major faults and F4, F5, F6, F7 and F8 are the minor faults. Faults are the major probable trapping mechanism in the field. Predicted field production from 1967 to 2011 using decline curve analysis shows high reserves in the reservoirs with Ellenburger having the highest reserves. Volumetric analysis shows that the Undifferentited Mississipian Limestone, Thirtyone, Fusselman, and Ellenburger reservoirs have reserve volumes of 40Bscf, 82Bscf, 71Bscf and 90Bscf, respectively.

(Keywords**:** reservoir, checkshots, porosity)

INTRODUCTION

Reserves estimation plays an important role to quantify the hydrocarbon in place of a field at any stage of the well history. Many wells have been abandoned in the past when technology used for exploitation was not as advanced as what we have today, some of these wells today still contribute greatly to the economy of such Countries. According to Holtz and Garret (1997) approximately 800 trillion cubic feet (Tcf) of natural gas was estimated to exist in the reservoir of the United States, yet only 538 tcf has been recovered. However, considering the reservoir of the Texas state land, only half of the original 20 Tcf of the natural gas in place has been recovered. Thus, detailed reservoir characterization of gas reserves is a valuable tool for increasing the production efficiency in the mature gas producing provinces of the United States.

In this study, we have used the wireline logs, 3-D seismic data and production record to evaluate the gas reserve of West Waha and Worsham-Bayer fields area of the southeastern Delaware Basin, West Texas (Figures 1 and 2) by determination of rock volume (hydrocarbon saturated portion) from area, average porosity, determination of water saturation to obtain hydrocarbon saturation and volume correction of hydrocarbon at atmospheric pressure and temperature, formation volume factor and recovery factor. These were supported with the production history data, using Arp's equations for the estimation of reserves

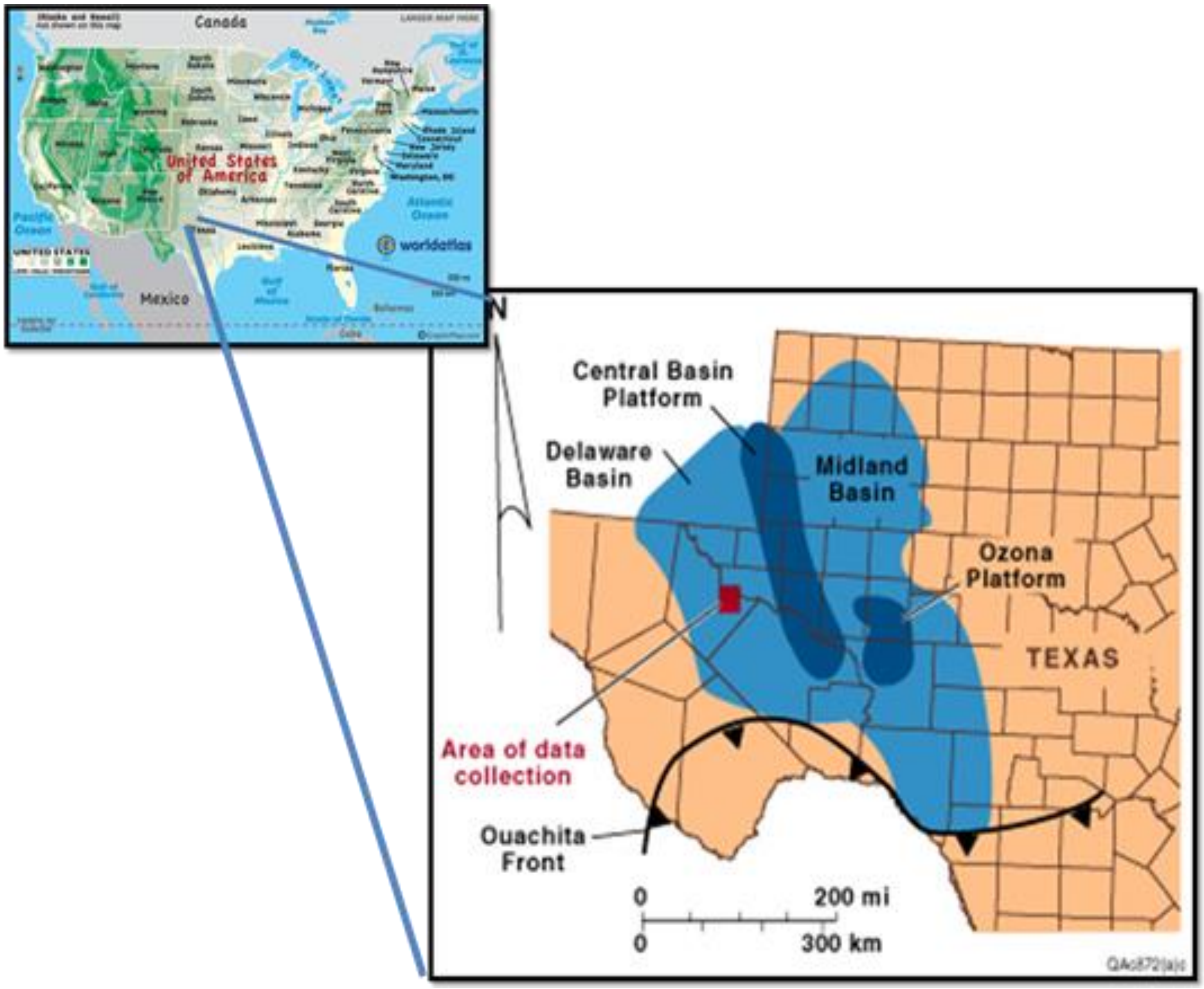
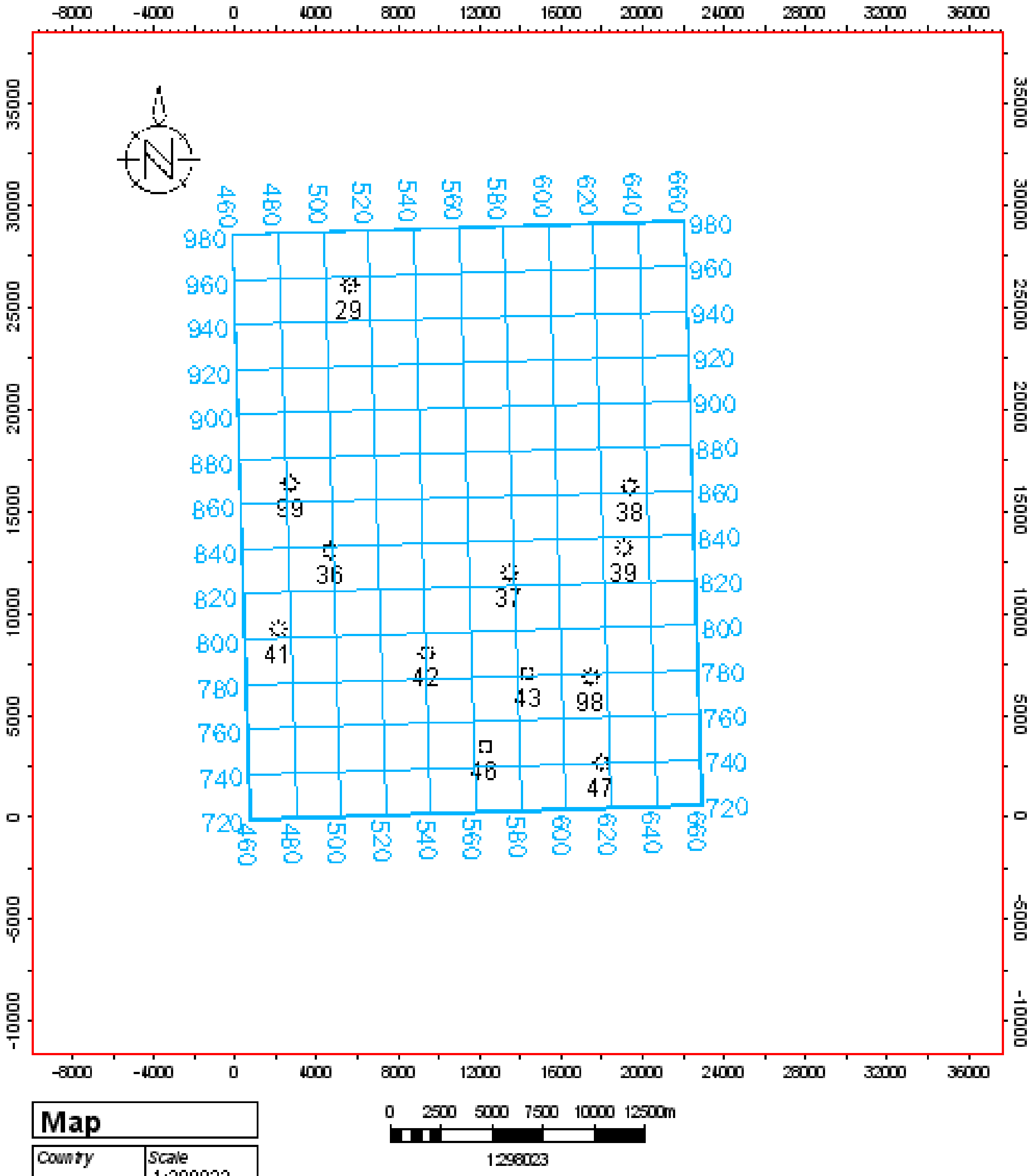


Figure 1: Map of the United State and location of SE Delaware Basin (b) Study area, Southeastern Delaware Basin, in the vicinity of West Waha and Worsham-Bayer fields.

The knowledge of reservoir dimension is an important factor in quantifying producible hydrocarbon (Schlumberger, 1989). Among the needed information includes the thickness and area extent of the reservoir. These parameters are important because they serve as veritable inputs for reservoir volumetric analysis, that is, the volume of hydrocarbon in place (Edward, 1988). Precise determination of reservoir thickness is best obtained on well logs, especially using the gamma ray and resistivity logs (Asquith, 2004).

Because almost all oil and gas produced today come from accumulations in the pore spaces of lithologies like sandstones, limestone or dolomites, the gamma ray log can come in handy to help in lithology identification, that is to differentiate between the reservoir rock (sand or carbonates) and the embedding shale (Asquith, 2004).

The resistivity log on the other hand, can be used for determining the nature of interstitial fluid, that is, differentiating between (saline) water and hydrocarbon in the pore spaces of the reservoir rocks. Since these logs are recorded against depth, the hydrocarbon-bearing interval can be determined.



Map

Country	Scale 1:298023
Block	Contour Inc
License	User name Admin
Model name	Date 04/17/2012
Horizon name	Signature

Figure 2: Base-map Showing Locations of the Wells.

Accurate mapping of the lateral dimension of the reservoir on the other hand, can be obtained from well logs, where abundantly available, or direct hydrocarbon indicators (Brown et al, 1984). To use well logs to map the lateral dimension of the reservoir, the gas-oil and oil- water contacts are located on structure maps, (Cofeen, 1984).

LOCATION AND GEOLOGY OF THE STUDY AREA

Delaware basin is located in West Texas and Southern New Mexico and it is famous for its large oil fields having the shallower Midland Basin to the east and the much smaller Marfa Basin to the southwest. All the three are south of the equator, north of the Oachita Mountain of mid Texas and part of the northern Continent Laurasia (Figure 3).

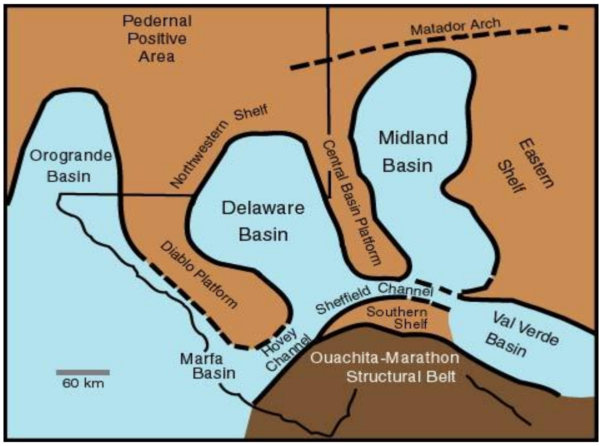


Figure 3: Main Features of the Permian Basin Region (adapted from Ward et al., 1986).

Structurally, the Delaware, Midland, and Marfa were foreland basins created when the Ouachita Mountains were uplifted as the Supercontinent Pangaea got broken down into Laurasia and Gondwanaland. The Ouachita Mountains formed a rainshadow over the basins, and a warm shallow sea flooded the surrounding area.

Cambrian rifting along the southern margin of North America formed a broad shallow-water platform in an area that covered much of southern West Texas during the Ordovician (Ewing, 1991). Carbonate sediments of the Ellenburger Group transgressed over Precambrian basement and reached thicknesses of nearly 1,750 ft., this was succeeded by the deposition of sandstone and shale of the Simpson group after widespread karsting and erosion of the Ellenburger group (Keran, 1990). Next to this was deposition of carbonate rocks and fine-grained siliciclastic rocks of the Montoya Formation, Fusselman Formation, Wristen Group, and Thirtyone Formation (Figure 4).During Late Devonian and Early Mississippian time, anoxic conditions resulted in deposition of the Woodford Formation (Wright,1979). After which clear-water sedimentation returned and Mississippian carbonate rocks were deposited (Jones, 1953; Wright, 1979).

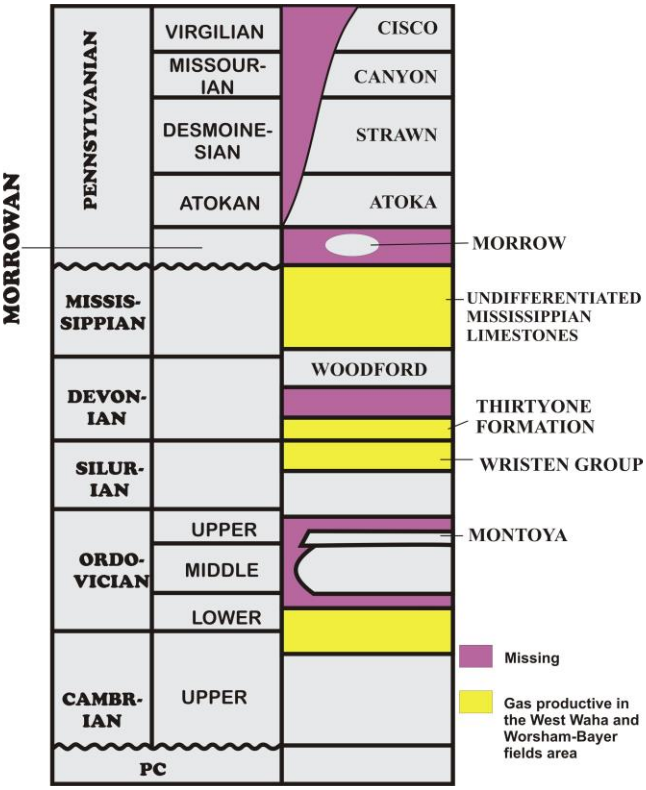


Figure 4: Stratigraphic Column for the Delaware Basin (modified from Kosters and others, 1989; Ruppel and Holtz, 1994).

Beginning in Late Mississippian and continuing through Late Pennsylvanian time, regional tectonic deformation associated with the Ouachita Orogeny resulted in major structural deformation in West Texas. Uplift of the Central Basin Platform resulted in partitioning of West Texas into the Delaware and Midland Basins (Hills, 1985; Ewing, 1991). Complex thrust faulting was associated with this uplift, structural rotation, and left-lateral strike-slip deformation in the southern part of the Delaware Basin, in the vicinity of West Waha and Worsham-Bayer fields. Folding and faulting associated with this deformation produced structures that in many areas provide traps for pre-Mississippian reservoirs (Schumaker, 1992).

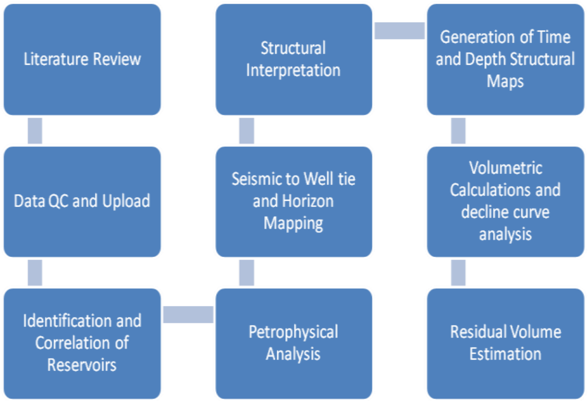
West Waha and Worsham-Bayer fields in the southeastern Delaware Basin were noted for carbonate sedimentation through Pennsylvanian and earliest Permian (Wolfcampian) time. Through most of the Permian, however, sedimentation in the Delaware Basin was dominated by deep-water siliciclastic deposition, whereas carbonate-platform sediments were deposited along the rim of the Delaware Basin and on the Central Basin Platform (Jones,1953; Wright,1979).

DATA SET AND METHOD OF STUDY

The dataset was received from Bureau of Economic Geology at the University of Texas, Austin, TX through the Sunrise Foundation, Nigeria. The data was acquired from the West-Waha and Worsham Bayer field area of Southwestern Texas. The dataset consist of 3D seismic data which contains 261 lines of 201 traces each, formatted as a 16-bit integer. The time range is 0 to 4 s at a sample rate of 4 ms. The time range interval was shifted with a multiplier of 10, which made it 40ms for proper view. The maximum amplitude value is 32,766, the minimum amplitude is -32,768, and the average amplitude value is 3.61. Well logs for 11 wells, including a check-shot survey for well no. 37 and a directional survey for well no. 29, are provided in the data set.

Production data up to November 1996 are provided for the wells within. The Gas productions are presented in a monthly production and cumulative production in units of thousands of standard cubic feet (Mscf), millions of standard cubic feet (MMscf), and billions of standard cubic feet (Bscf). Decline curve analysis using the Arp's equation was used to provide information about future production rate; cumulative rate and most importantly about the remaining gas reserves.

Petrel software was used to carry out seismic interpretation and well log correlation while Landmark Geographix (Prizm module) was used for the petrophysical study. Other software resources are Microsoft Excel, Notepad and Wordpad for editing some of the data set. The following workflow was adopted for the study:



RESULTS AND DISCUSSIONS

Preliminary study on the well logs revealed four hydrocarbon-bearing reservoirs in which the following studies was carried on:

Well Correlation

Well log correlations using gamma ray, spontaneous potential, resistivity, caliper, sonic, neutron and density logs reveals four hydrocarbon bearing zones, the top of which were defined using stratigraphical approach. Stratigraphic marker beds were used to delineate the parameter intervals (reservoirs) from the logs and were correlated across the field. The four hydrocarbon bearing zones (Ellenburger, Fusselman, Thirtyone, and Mississipian) after correlation shows variation in thickness, generally the reservoir thickness varies or decreases from the North to South. Well 29 (deviation data was provided for this well) is the deepest of all the wells and it sees the entire hydrocarbon or gas reservoir with Ellenburger being the thickest. Ellenburger has a thickness of about 1700ft and have an average thickness of about 750ft in the other wells (Figures 5 and 6).

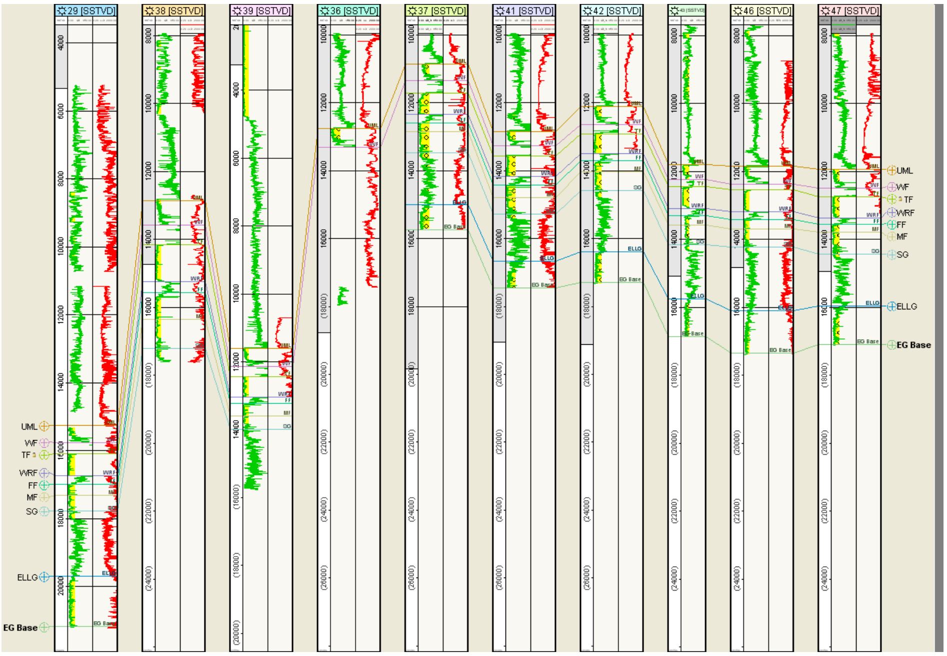


Figure 5: Composite Well Correlation of the Wells Across the Field.

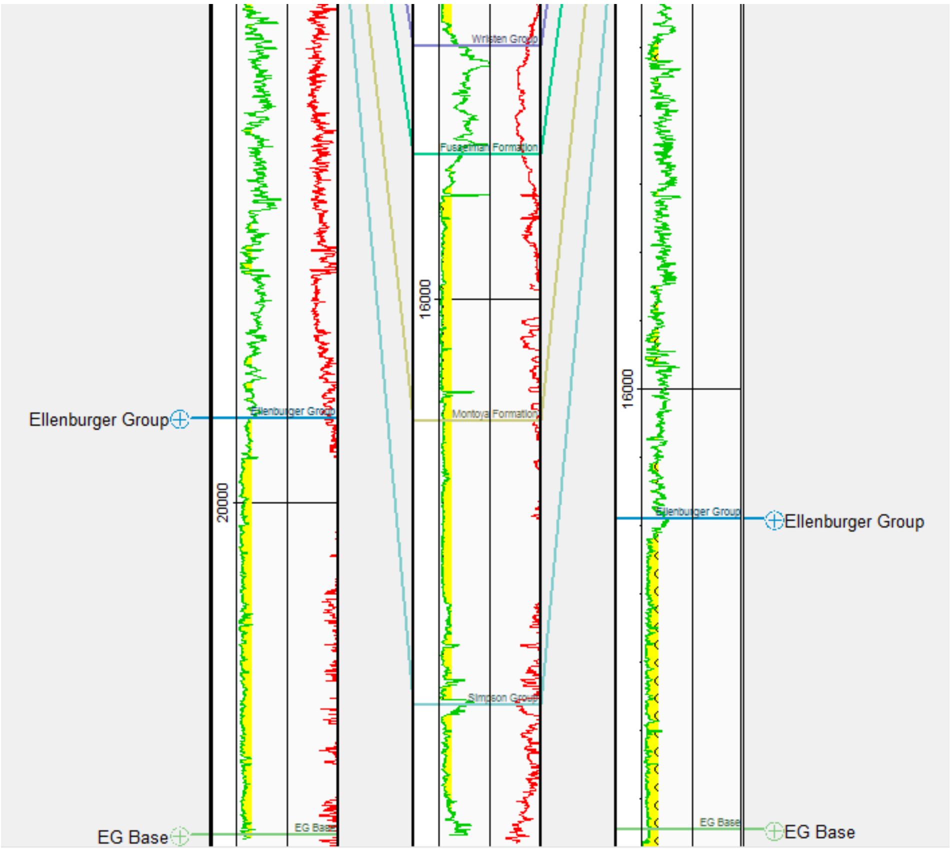


Figure 6: Well Logs within the main Ellenburger Group Reservoir**.**

Petrophysics

Petrophysical parameters such effective porosity, water saturation, net to gross, net pay, and shale volume were calculated using Prizm module in Landmarks Geographix software. Out of the 11 wells given, only 9 have enough log data for petrophysics analysis.

Well 29 and 41 have a combination of RHOB (bulk density) & NPHI as their porosity logs which are used to calculate the effective porosity and other derived parameters. All other wells have sonic porosity and RHOB as their porosity log which are used to calculate the effective porosity and other derived parameters. Porosity was also seen to be high in this reservoirs and this could be as a result of high karsting, breciation. and dissolution in the reservoir as proposed by Keran, 1988.

The average PHI cut off for this calculation is 0.15, the average water saturation cut off for this calculation is 0.2, the irreducible water saturation value is 0.1 while the average volume of shale cutoff is 0.2, gamma ray clean is 30, and the average gamma ray shale value is 90. Average HCPV is 0.28.

The fluid contacts for the reservoir, GWC and ODT were used to demarcate the basal extent of the hydrocarbon column in the reservoirs. These contacts were determined using the resisitvity logs and porosity logs. The petrophysical results for the wells are shown in Tables 1 to 4.

It is only in Undifferentiated Mississippian Limestone (UML) that gas water contact (GWC) is encountered; others have oil down to (ODT) scenario.

Table 1: Petrophysical Parameters for UML Reservoir.

UML	TOP MD(ft)	BASE MD(ft)	GROSSINT	GROSSRES	NETRES	NETPAY	N/G PAY	N/GRES	PHIPAY	SWPAY	VSHLPAY	GWC/ODT(ft)
29	15410.3	15907.1	495.787	259.623	167.123	105.123	0.212	0.337	0.194	0.352	0.023	ODT
36	12758.1	13307.7	549.6	419.5	40.5	39.5	0.072	0.074	0.232	0.209	0.003	GWC -13172
37	13310.4	13794.6	484.2	365.5	40.5	40	0.083	0.084	0.243	0.188	0.015	GWC -13713
39	11592.3	12144.4	552.1	476.45	41.95	40.95	0.074	0.076	0.226	0.078	0.001	GWC -12035
41	12838.7	13274.2	435.5	359.55	116	116	0.266	0.266	0.233	0.054	0.001	GWC -13134
42	12117.5	12642.4	524.9	408	67.5	41.5	0.079	0.129	0.29	0.431	0	ODT
46	11841.7	12376.3	534.6	388.05	101.5	101.5	0.19	0.19	0.333	0.033	0.003	GWC -12222
47	11936.3	12490.4	554.1	445	214	194.5	0.351	0.386	0.268	0.225	0.026	GWC -12364

Table 2: Petrophysical Parameters for Thirtyone Formation Reservoir

ZONE 31	TOPMD	BASE MD	GROSSINT	GROSSRES	NETRES	NETPAY	N/G PAY	N/GRES	PHIPAY	SWPAY	VSHLPAY	GWC/ODT
29	16244.2	16892.2	647.371	526.055	108.055	70.555	0.109	0.167	0.177	0.346	0.033	ODT
37	14146.5	14778.4	631.9	631.9	124	120	0.19	0.196	0.241	0.144	0.003	ODT
38	14150.1	15248.6	1098.5	1098.5	527	526	0.479	0.48	0.232	0.069	0.002	ODT
39	12438	13034.9	596.9	596.9	65	65	0.109	0.109	0.185	0.062	0.001	ODT
41	13556.1	14176.3	620.2	620.2	121.5	92	0.148	0.196	0.221	0.053	0	ODT
42	12912.7	13515.3	602.6	458.55	185	94	0.156	0.307	0.311	0.461	0	ODT
46	12543.5	13181.2	637.7	637.45	461.95	461.95	0.724	0.724	0.314	0.031	0.005	ODT
47	12723.7	13378.9	655.2	494.55	87.55	87.55	0.134	0.134	0.132	0.26	0.007	ODT

Table 3: Petrophysical Parameters for Fusselman Reservoir.

FUSSEL	TOPMD	BASE MD	GROSSINT	GROSSRES	NETRES	NETPAY	N/G PAY	N/GRES	PHIPAY	SWPAY	VSHLPAY	GWC/ODT
29	17139.4	17450.7	311.06	311.06	276.56	256.56	0.825	0.889	0.27	0.261	0.002	ODT
37	15035	15283.9	248.9	246.9	14	14	0.056	0.056	0.268	0.168	0	ODT
38	15569.4	16362.7	793.3	783.3	134.95	32.5	0.041	0.17	0.277	0.124	0.07	ODT
46	13416.5	13667.3	250.8	250.8	228.8	228.8	0.912	0.912	0.252	0.045	0.002	ODT

Table 4: Petrophysical Parameter for Ellenburger Group Reservoir.

ELLEN	TOPMD	BASE MD	GROSSINT	GROSSRES	NETRES	NETPAY	N/G PAY	N/GRES	PHIPAY	SWPAY	VSHLPAY	GWC/ODT
29	19845.8	21238.1	1391.227	1365.349	163	152	0.109	0.117	0.289	0.186	0.007	ODT
37	17457.5	18163.3	705.8	689.3	81.5	80.5	0.114	0.115	0.265	0.186	0.033	ODT
41	16674.6	17432.9	758.3	658.15	89	85	0.031	0.117	0.26	0.04	0.12	ODT
42	16381	17304.5	923.5	758.9	76	90	0.024	0.082	0.29	0.17	0.007	ODT
46	16082	17384.7	1302.7	1290.2	42.5	41.5	0.032	0.033	0.185	0.095	0.181	ODT
47	16017.1	17111.6	1094.5	976.26	67.4	220	0.12	0.062	0.192	0.034	0.03	ODT

SEISMIC INTERPRETATION

The different reservoir bodies picked from the well log data all have a corresponding seismic reflection time of arrival. The well picks were tied and posted to the seismic sections using time-depth pair (check shot) provided for well 37. After plotting the check shot data in two-way time against depth and the resulting equation used to calculate time equivalent of well tops to be posted on seismic sections. The wells were then tied to seismic data. A synthetic seismogram was carried out to show the reflection on seismic.

The top and base of the hydrocarbon bearing zones (Ellenburger, Fusselman, Thirtyone, and Undifferentiated Mississipian Limestone) determination using the reflection characteristics of the 3-D seismic volume, stratigraphic indicators and the nature of the gamma ray curves that characterize this interval (Figures 7 and 8) shows the reflection of the reservoirs on seismic. The lithologies penetrated by the studied wells were determined by setting the cut-off point at 65 API on the gamma ray logs combined with the porosity logs and resistivity logs. The horizons picked across the field were loop-tied.

Major and minor faults were identified, traced and assigned using the petrel software. The faults which were wicked at an interval of 10 on the in-lines section were subsequently reflected on the cross-lines sections. A total of 3 major faults were picked which formed the structural framework of the field (Figure 9). The major fault types are normal faults and in some cases thrust faults. In the deeper section of the field, anticlinal structures are responsible for field wide structural framework. There are 5 other minor faults (F4-F8), which are listric faults.

Folding and faulting associated with the deformations produced structures that in many areas provide traps for Pre-Mississipian reservoirs. Based on the faults picked and the horizon mapped, a time map was generated for the top and bottom of each reservoir and this was modeled to a depth structural map to identify our closures for volumetric analysis.

These horizons were later correlated in the 3-D seismic volume in order to produce time and depth structure map of the horizons. After correlation, a model of the produced map was generated (Figure 9).

Volumetric and Reservoir Estimate

The process of estimating oil and gas reserves for a producing field continues throughout the life of the field.

The volumetric method entails determining the physical size of the reservoir, the pore volume within the rock matrix, and the fluid content within the void space. This provides an estimate of the hydrocarbons-in-place, from which ultimate recovery can be estimated by using an appropriate recovery factor. Each of the factors used in the calculation have inherent uncertainties that, when combined, cause significant uncertainties in the reserves estimate.

The parameters derived from the petrophysical analysis, the 3-D seismic interpretation and the reservoir attribute such as the net pay, effective porosity analysis were used to calculate the total gas in place and the total recoverable reserve for the fields' reservoirs.

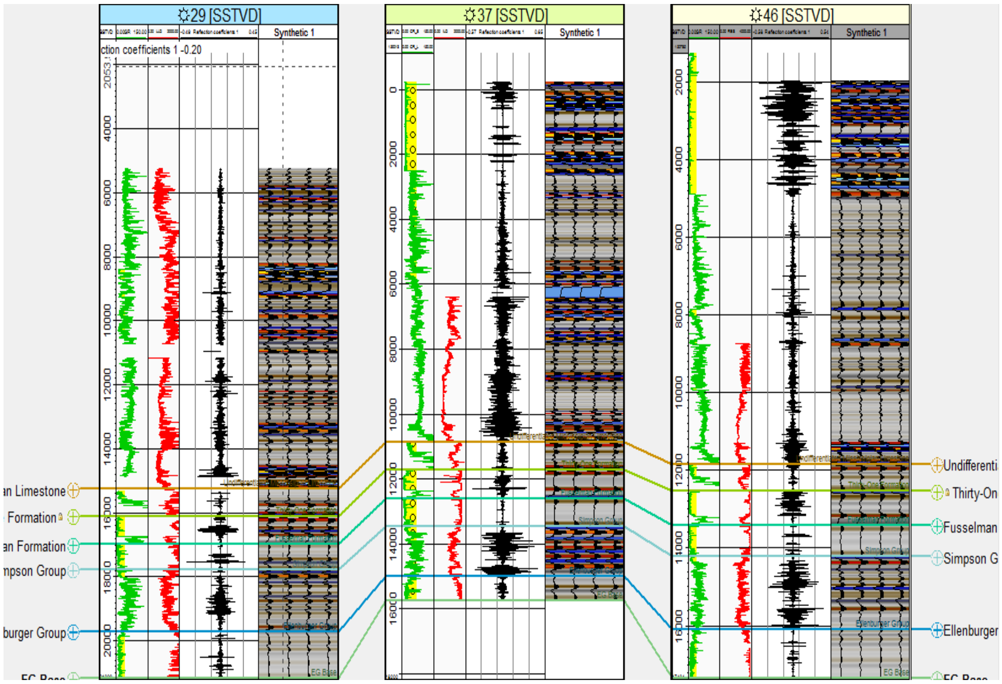


Figure 7: A Synthetic Seismogram.

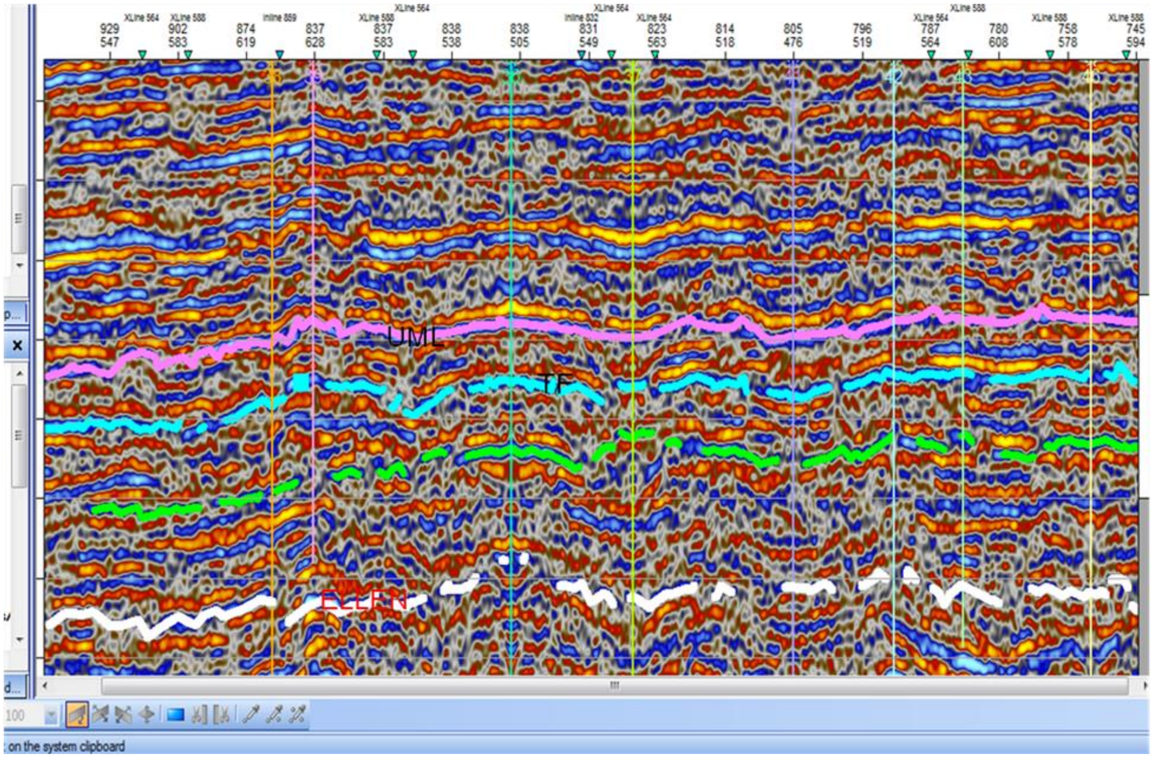


Figure 8: Horizons Picked for Each of the Reservoir.

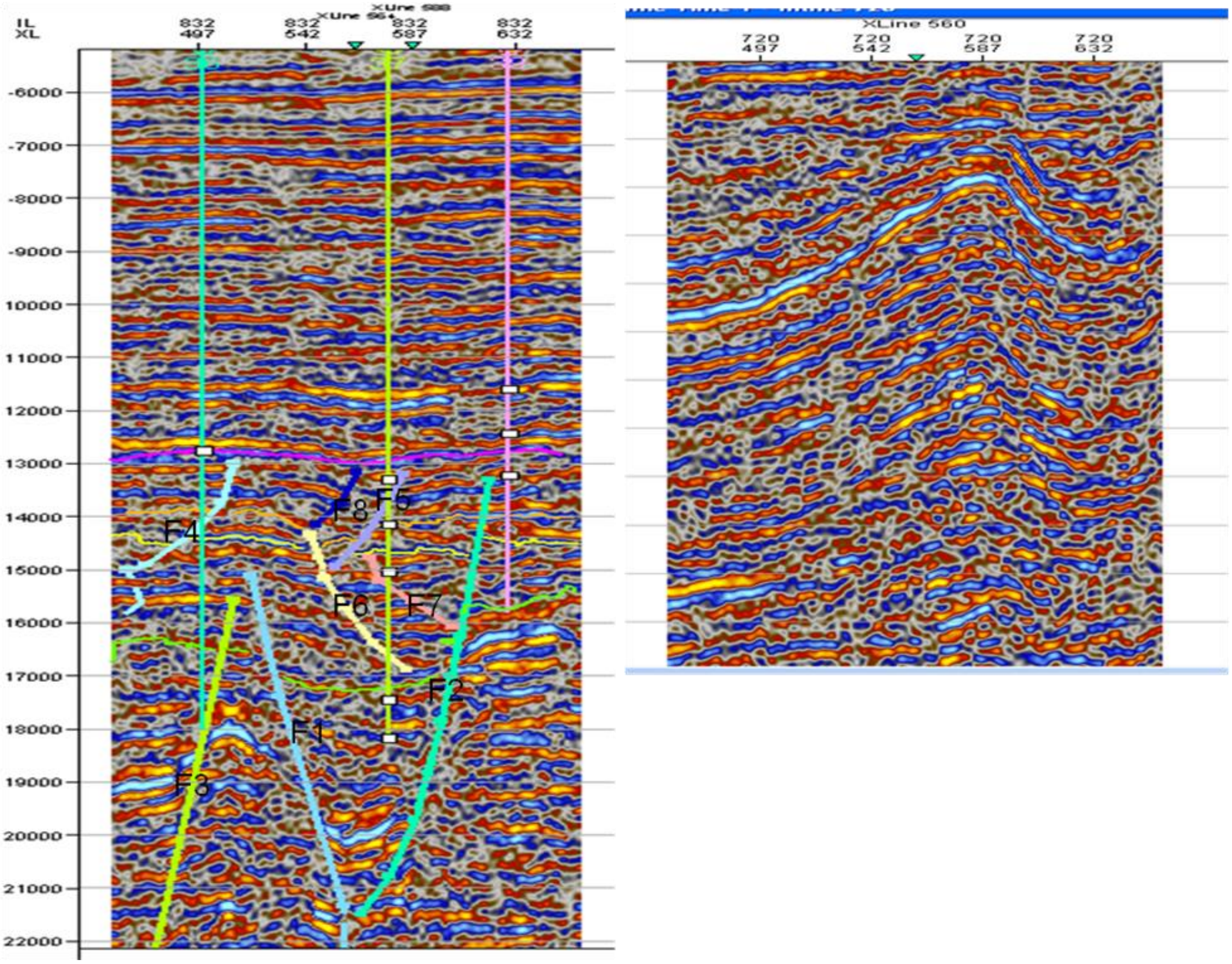


Fig 9: Interpreted Faults showing on inline 832 and Anticlinal Structures on inline 720.

The recovery factor [30] and Gas Formation Volume Factor [1.280] used for the volumetrics calculation were derived from past works (Platt and Lewis, 1969) and (Bowker, 2007) using the following formular:

$$OGIP = 43560 \times Area \times H \times \phi \times (1 - S_W) \times NTG \ldots\ldots \text{Equation 1}$$

$$STOGIP = \frac{OGIP}{B_g/FVF} \times RF \ldots\ldots \text{Equation 2}$$

Where:

OGIP=Original gas in place

Area=hydrocarbon closure

H=Netpay

ϕ=porosity

S_w=water saturation

NTG=Net/Gross

STOGIP=Stored tank gas in place

B_g/FVF=formation volume factor

RF=Recovery factor

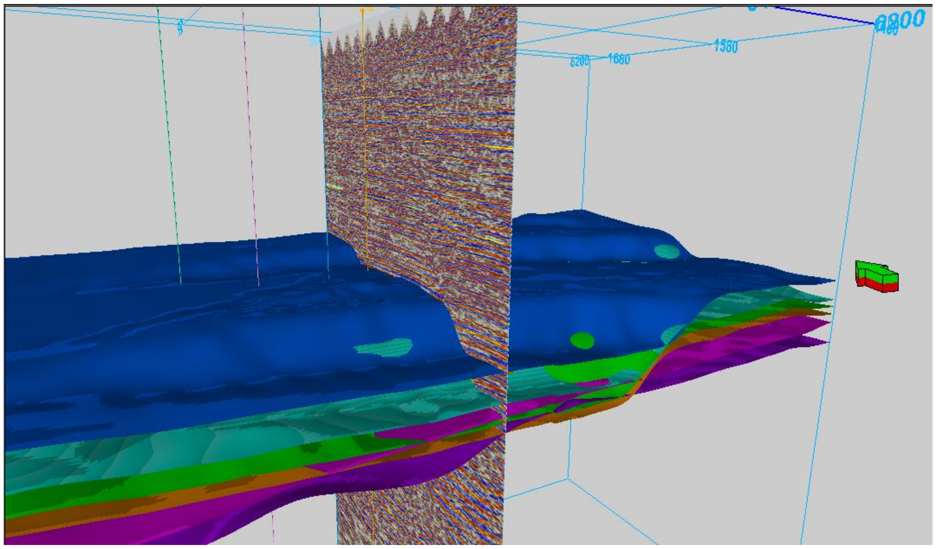


Figure 10: 3-D Visualization of the Horizons Generated.

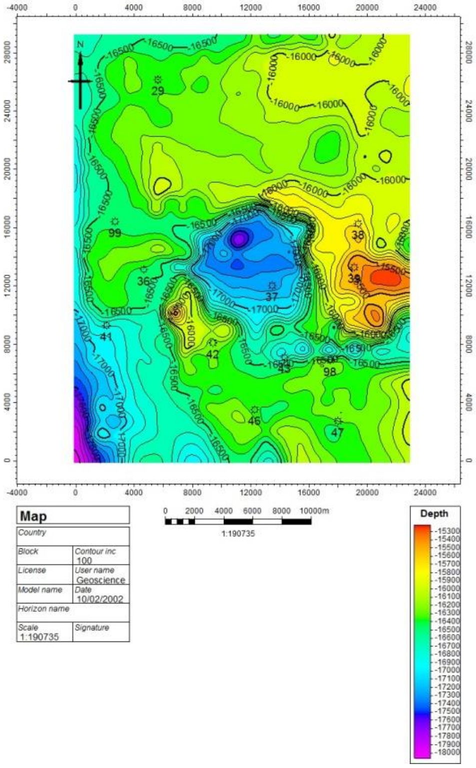


Figure 11: Depth Structural Map for Ellenburger Group Reservoir.

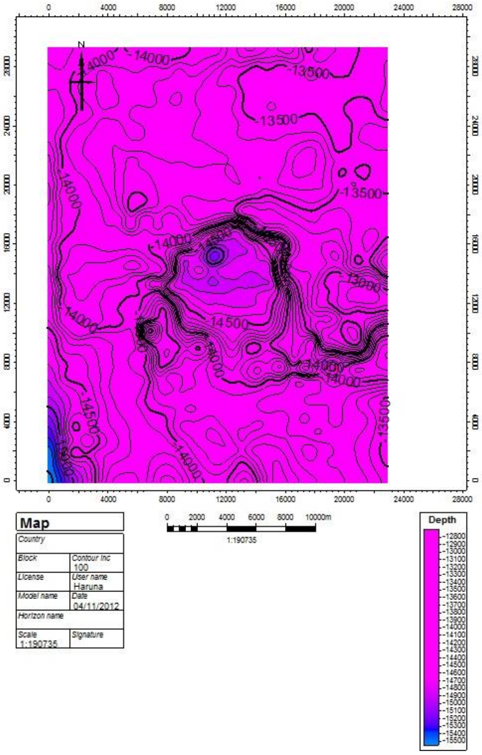


Figure12: Depth Structural map for Fusselman Reservoir.

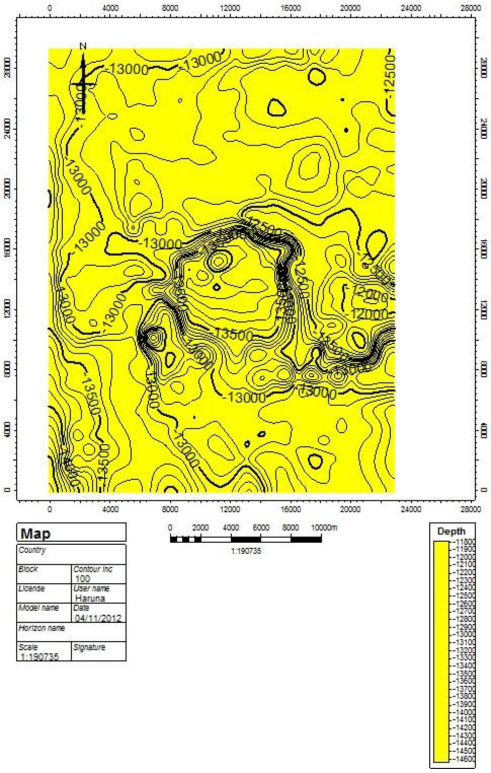


Figure 13: Depth Structural Map for Thirtyone Reservoir.

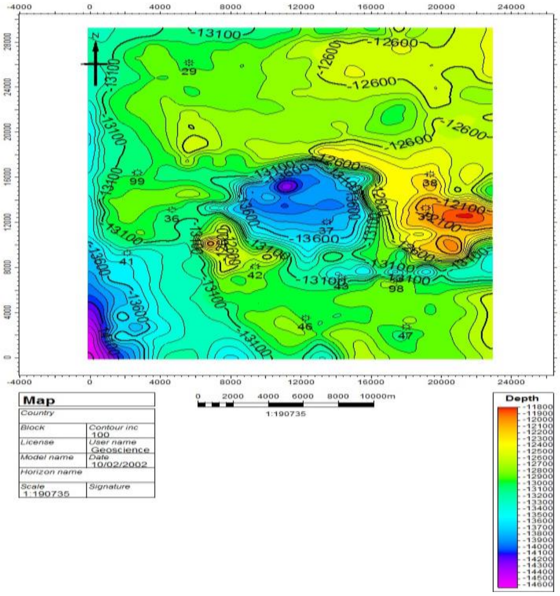


Figure14: Depth Structural Map for Undifferentiated Mississipian Limestone Reservoir.

Graphical results for each of the wells Cumulative Gas production versus production dates were plotted to estimate the reserve of the field. The principal results obtained in this research include: the petrophysical analysis result for porosity and the reservoir attribute analysis result for thickness determination, volumetric analysis result for gas in place and recoverable reserve estimation (Tables 5-8), time-depth structure maps were used to map out prospects for secondary re-drill in the fields and production data graphical results showed natural gas productivity pattern within the year range of 1967-2011 by plotting the wells Cumulative Gas MMscf versus production dates using the hyperbolic equation of Arp's decline curve. T

he Arp's equation proposed for decline analysis was used. The field of study was discovered to follow the hyperbolic equation proposed by Arp's. This was used to plot the production of the wells from 1967 to 2011, using the production data provided for the wells from 1967 to 1996. This method of decline was used for this study, production history provided with the data set was from 1967 to 1996. This production history was recorded on a monthly basis in both gas per month production and cumulative gas per month production.

This was used to plot the production history to know which of the Arp's equation does the field agree to (Figure 15) and after the generation of the type curve, it was discovered that all the wells follows the Arp's hyperbolic equation.

A cumulative hyperbolic equation was used to predict the future of the wells and a production curve was plotted (Figures 16 and 17).

Table 5. Volumetric Parameters for Undifferentiated Mississipian Limestone.

RESERVOIR	WELL	AREA(acres)	NET PAY(ft)	NTG	ϕ%	S_W	STOGIP(Bscf)
UML	29	4501	125.12	0.18	20	0.2	12
	39	4117	45.7	0.07	23	0.2	8
	37	1533	40.05	0.08	24	0.2	9
	41	1676	116.0	0.27	23	0.2	11
Total							40

Table 6: Volumetric Parameters for Thirtyone Reservoir.

RESERVOIR	**WELL**	**AREA(acres)**	**NET PAY(ft)**	**NTG**	**ϕ%**	S_W	**STOGIP(Bscf)**	**RESERVE(Bscf)**
THIRTYONE	29	2352	70	0.11	24	0.3	35	30
	38	2300	526	0.48	23	0.1	28	21
	39	2250	65	0.11	24	0.2	18	16
	47	1674	87	0.14	22	0.2	17	15
Total							98	82

Table 7: Volumetric Parameters for Fusselman Reservoir.

RESERVOIR	**WELL**	**AREA(acres)**	**NET PAY(ft)**	**NTG**	**ϕ%**	S_W	**STOGIP(Bscf)**	**RESERVE(Bscf)**
FUSSELMAN	29	2443	256	0.83	27	0.2	25	24
	46	1998	228	0.92	24	0.2	18	14
	38	1081	32.5	0.04	25	0.1	23	18
	39	1200	61	0.05	27	0.3	21	15
Total							87	71

Table. 8: Volumetric Parameters for Ellenburger Group Reservoir.

RESERVOIR	WELL	AREA(acres)	NET PAY(ft)	NTG	ϕ%	S_W	STOGIP(Bscf)	RESERVE(Bscf)
ELLENBURGER	29	5100	281	0.11	28	0.2	48	40
	46	2530	73	0.32	26	0.4	24	20
	37	2112	152	0.06	22	0.1	29	10
	47	2209	220	0.08	24	0.2	34	20
Total							135	90

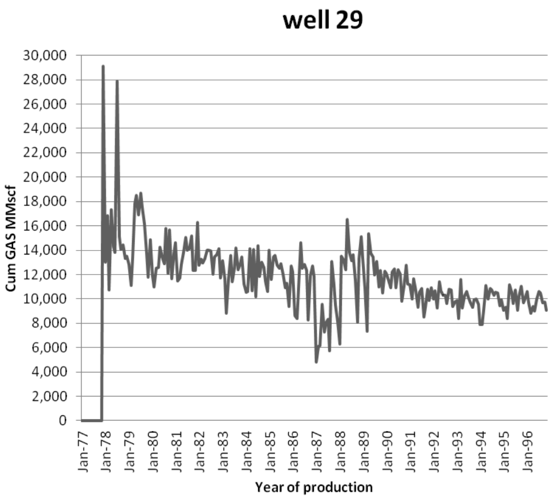


Figure 15: Type Curve Generated for a Well using the Production History Provided**.**

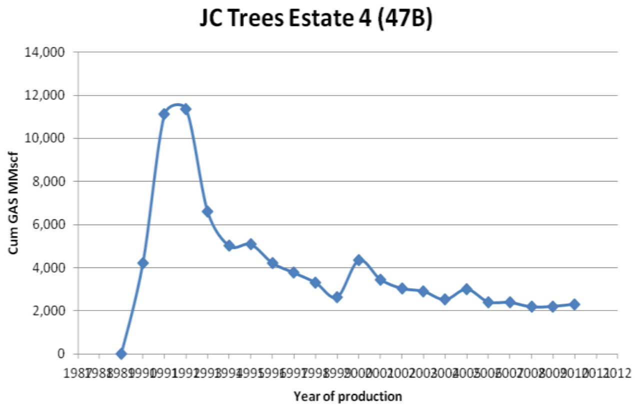


Figure 16: Plot of Cumulative against Year of Production for Well 47B.

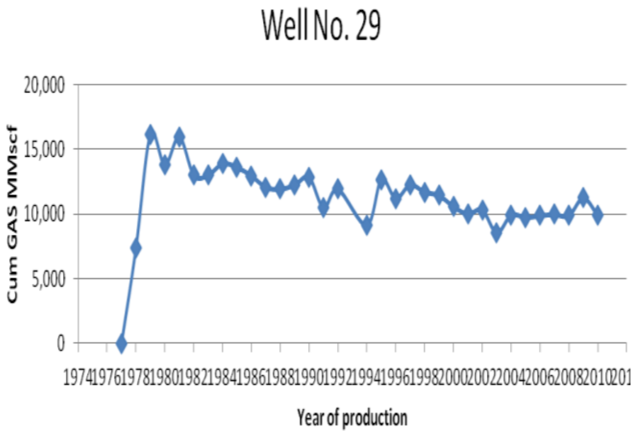


Figure 17: Plot of Cumulative against Year of Production for Well 29.

CONCLUSIONS

The integration of well and seismic data provides insight to reservoir hydrocarbon volume which may be utilized in exploration evaluations and in well bore planning. From the analysis of the wireline logs of the hydrocarbon bearing zones, four reservoirs were identified in which 3-D structural interpretation and estimation of the volume of hydrocarbon-in-place was carried out. It was discovered that the reservoir thickness varies from the West to the East. Though, there is variation in the reservoir thickness, petrophysical parameters evaluation shows that the thin beds also contribute large amount of hydrocarbon to the reservoir.

Volumetric analysis result for gas in place and recoverable reserve estimation, time-depth structure maps resulted in the mapping out of prospects for secondary re-drill in the fields and production data graphical results showed natural gas productivity pattern within the year range of 1967-2011 after plotting the wells Cumulative Gas MMscf versus production dates.

Production data interpretation shows decrease in natural gas productivity from the well as the year increases with Ellenburger being the highest producing reservoir. Thirtyone, fusselman and Undifferentited Mississipian Limestone also contribute an appreciable amount of natural gas.

Faults interpretations show that the F1 to F3 are the building framework for the field, they also trend in a N-S direction, while F4 to F8 serves as probable traps for most of the hydrocarbon. Folding and faulting associated with the deformation produced structures that in many areas provide traps for Pre-Mississipian reservoirs.

ACKNOWLEDGEMENTS

The authors are grateful to Sunrise Foundation for the assistance in the data set used for this study. NAPE is also acknowledged for the NAPE-UAP grant awarded to the first author.

REFERENCES

1. Ewing, T. E. 1991. “The Tectonic Framework of Texas: The Tectonic Map of Texas". Bureau of Economic Geology, The University of Texas at Austin: Austin, TX. 36 p.

2. Frenzel, H.N., R.R. Bloomer, R.B. Cline, J.M. Cys, J.E. Galley, W.R. Gibson, J.M. Hills, W.E. King, W.R. Seager, F.E. Kottlowski, T.S. Thompson, III, G.C. Luff, B.T. Pearson, and D.C. VanSiclen. 1988. “Chapter 11: The Permian Basin Region”. In: Sloss, L. L. (ed.). *Sedimentary Cover-North American Craton, The Geology of North America, v. D-2.* Geological Society of America: Washington, D.C. 261-306.

3. Hills, J.M. 1985. “Structural Evolution of the Permian Basin of West Texas and New Mexico”. In: Dickerson, P. W., and W.R. Muehlburger (eds.). *Structure and tectonics of Trans-Pecos Texas*. West Texas Geological Society. 85-81, 89-99.

4. Holtz, M.H. and C.M. Garrett, Jr. 1997. “Play Analysis and Resource Assessment of Texas State Lands”. In: Major, R.P. (ed.). “Oil and Gas on Texas State Lands: An Assessment of the Resource and Characterization of Type Reservoirs”. The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 241: 1-30.

5. Jones, T.S. 1953. *Stratigraphy of the Permian Basin of West Texas*. West Texas Geological Society. 57.

6. Kerans, C. 1988. “Karst-Controlled Reservoir Heterogeneity in Ellenburger Group Carbonates of West Texas”. *American Association of Petroleum Geologists Bulletin*. 72(10):1160-1183.

7. Kerans, C. 1990. “Depositional Systems and Karst Geology of the Ellenburger Group (Lower Ordovician), Subsurface West Texas”. The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 193, 63.

8. Kosters, E.C., D.G. Bebout, S.J. Seni, C.M. Garrett, Jr., L.F. Brown, Jr., H.S. Hamlin, S.P. Dutton, S.C. Ruppel, R.J. Finley, and N. Tyler. 1989. “Atlas of Major Texas Gas Reservoirs: The University of Texas at Austin, Bureau of Economic Geology”. 161.

9. Ruppel, S.C. and M.H. Holtz. 1994. “Depositional and Diagenetic Facies Patterns and Reservoir Development in Silurian and Devonian Rocks of the Permian Basin”. The University of Texas at Austin, Bureau of Economic Geology Report of Investigations. 216:89.

10. Schlumberger. 1989. *Log Interpretation, Principles and Application*: Schlumberger Wireline and Testing: Houston, TX. 21-89.

11. Schumaker, R.C. 1992. “Paleozoic Structures of the Central Basin uplift and adjacent Delaware Basin, West Texas”. *American Association of Petroleum Geologists Bulletin*. 76:1804-1824.

12. Ward, R.F., C.G. St.C. KendallL, and P.M. Harris. 1986. “Upper Permian (Guadalupian) Facies and their Association with Hydrocarbons Permian Basin, West Texas and New Mexico”. *American Association of Petroleum Geologists Bulletin*. 70:239-262.

13. Wright, W. F. 1979. “Petroleum Geology of the Permian Basin”. West Texas Geological Society Publication No. 79-71: 98.

ABOUT THE AUTHORS

Kehinde Haruna, obtained his Masters degree in petroleum geology from University of Ilorin.

Sola Ojo, is an Associate Professor of Geology at the Department of Geology University and has published over 40 articles in learned journals.

Wasiu Odufisan, is a practicing geophysicist and has mentored several young academics and professionals.

SUGGESTED CITATION

Haruna, K.A., O.J. Ojo, and W. Odufisan. 2014. **“**Subsurface Mapping and Reservoir Evaluation of West Waha and Worsham-Bayer Field Area of Southeastern Delaware Basin, West Texas”. *Pacific Journal of Science and Technology.* 15(1):360-374.

Pacific Journal of Science and Technology