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Prediction of Inter-Well Petrophysical Properties from Seismic Model: A Case of Egbem Field, Niger Delta, Nigeria

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ABSTRACT

We have generated a seismic model for the prediction of inter-well petrophysical properties of Egbem Field; in the Niger Delta, Nigeria. Acoustic Impedances (AI) were calculated from sonic and density logs in the available 24 wells. Reflection Coefficients (RC) determined from the acoustic impedances were convolved with modelled wavelet to produce synthetic seismograms at various well locations. A top structure map of a reservoir from the field was used to define the position of faults, which served as key pillars in gridding the reservoirs of the field into geocellular blocks of 50 x 50 meters each. Petrophysical analysis of the field showed an average porosity of 24.8% and volume of shale of 19.9%. Petrophysical parameters were geostatistically distributed on the generated framework model using Sequential Gaussian Simulation (SGS). The result of the Acoustic Impedance classification reveals four lithologic facies namely, shale, sandy shale, shaley sand and sand facies. The facies model indicates high and low acoustic impedances for sand and shale respectively. This model indicates that sand which is a good reservoir is concentrated in the central part of the field. The result of synthetic seismic generation showed a very good match between acoustic impedance and lithology. Comparison of porosity obtained from the porosity model with conventional well log porosity showed similarities in their histogram distribution. Finally, Three-dimensional seismic model of Egbem Field has been constructed using log data from twenty four wells. The application of geostatistical analyses extrapolated and interpolated these log data to cover the entire field.

Keywords: Seismic, Modelling, Prediction, Petrophysical properties, Niger Delta

INTRODUCTION

Accurate prediction of petrophysical properties in wells is crucial for effective reservoir characterization and management in the oil and gas industry as these properties, such as porosity, permeability, volume of shale and fluid saturation etc provide essential insights into the reservoir's potential for hydrocarbon production. Alaei (2012) defined seismic forward modelling as seismic forward realization of a given geological model, while Anderson and Cardimona (2002) defined it as a computational process through which a geologic model of the subsurface is transformed into a synthetic reflection seismic record. Seismic modelling used in this study therefore refers to the generation of 3-dimensional seismic cube of the subsurface area from geophysical well log data.

Well log data are obtained from continuous measurement of specific rock properties which are penetrated within drilled well. Measurements are made by an appropriate instrument called sonde, which is attached to the end of a cable that is lowered into the well (Alexander, 2008). The parameters measured are in-situ, as the sonde moves up and down inside the well. These measured log data are subject to borehole irregularities such as time lapse between the drilling and logging of the borehole (Jarvis, 2006). In all cases, log data will require some editing, normalization, and interpretation before they can be used in any geophysical application (Walls et al., 2004).

However, log data are discrete and point measurements which do not give interwell petrophysical properties. Therefore, in seismic modelling using well log data, geostatistics becomes applicable as an interpolation and extrapolation method using values of given variable by estimation (Soleimani & Hashemi, 2011). This method has become a valuable tool in extrapolating geological data at discrete points i.e. log data to cover wider area. This is done based on the fact that advancement in geostatistics is now providing better understanding and determination of inter-well petrophysical properties.

In the prediction of inter-well petrophysical properties, there is the need to up- or down-scale data in other to increase the reliability of such prediction. This is because well-log data has medium vertical resolution (several centimeters) and least coverage (several centimeters) while seismic data has least vertical resolution (several meters) but maximum coverage (tens of kilometers). For these reasons, the data for this study were upscaled for better interpretation.

In the oil and gas industry, the non-availability of seismic data can greatly increase the risk associated with the industry in several ways. Firstly, this can result in uncertainty of the structural and lithological framework of the reservoir and secondly, uncertainty in the inter-well petrophysical properties can increase uncertainties associated with the determination of the hydrocarbon in place. The uncertainty associated with the areal coverage of a field can be ascertained using seismic data. Therefore, in this study, seismic model will be generated for the prediction of inter-well petrophysical properties in Egbem Field of Niger Delta, Nigeria.

The study area is located within the Niger Delta, on the northern part of the Gulf of Guinea, and at the southernmost edge of the Benue Trough (Corredor et al., 2005). Egbem Field is situated within the Coastal Swamp depobelt of the Niger Delta, about 26 kilometres northeast of Port Harcourt in the Eastern Niger Delta (Fig. 1). The field has total area coverage of 59.4 km^2 with twenty-four drilled wells (Fig. 1).

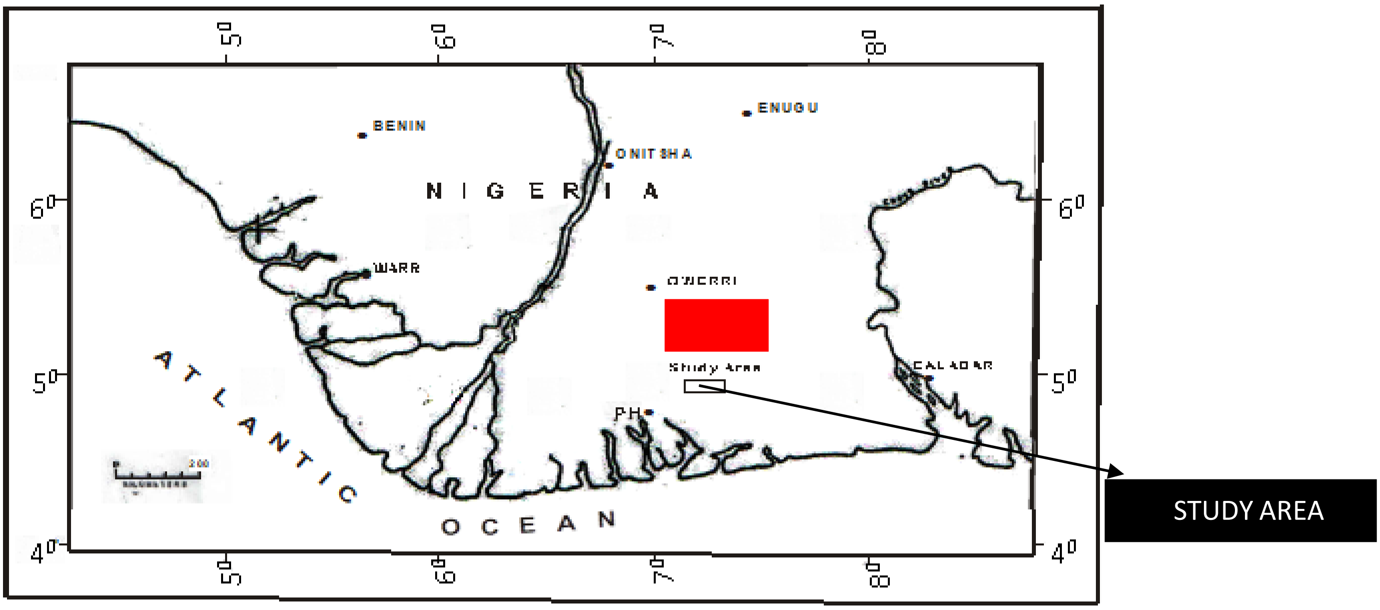

Fig. 1: The map of Niger Delta Province showing location of the study area

The study will focus on how to use only well log data to generate seismic models and thereby predict inter-well petrophysical properties of the field.
The result of this study will be beneficial to oil industries, especially when there is an incomplete dataset, such as absence of seismic data. It will particularly be beneficial to reservoir geologists in carrying out accurate characterization of reservoirs and proper prediction of petrophysical parametersleading to better estimation of hydrocarbon in place.

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MATERIALS AND METHODS

The data for this study are basically well data and a top structure map of a reservoir from a hydrocarbon bearing field in a Niger Delta Basin. The well data include well heads, well deviations and well logs of twenty four wells. The well heads contain such information as well identification, total depth of wells, Easting and Northing. The well deviations contain information such as well name, measured depth, dip, and azimuth, total vertical depth (TVD), Easting (X) and Northing (Y). The well logs are available in ASCII format to be loaded into Petrel software.

The well log data include gamma ray, density, resistivity, sonic and neutron logs. These wells are labelled EGB 001 – 024 (Table 3). The percentage availability of each of the log data are 100%, 100%, 70.8%, 16.7%, 50%, for gamma ray, resistivity, sonic, density, and neutron log respectively.

The well data were imported into the Petrel Software, quality checked and normalized as they were not acquired at the same time. This was followed by correlation of the available wells, establishing the various reservoirs of the field. Both gamma ray and resistivity logs were used for the wide field correlation. Two petrophysical parameters (porosity and volume of shale) were calculated from the well logs using appropriate equations (Anakwuba, et al., 2013). The shape of the wavelet used in the convolution process was determined (wavelet modelling) prior to the generation of synthetic seismogram. The Ricker zero phase was used in this study and its spectrum fulfils the Nyquist criteria (Saether, 2013) as follows:

$f_{max} \leq \frac{C_{min}}{2\Delta x}$..Eq. 1

Where

F_{max} = maximum frequency in the wavelet spectre

C_{min}= minimum velocity in the model

Δx= distance between two grid points in meters

Synthetic seismogram was generated by firstly, calculating the acoustic impedance (AI) and reflection coefficient (RC) from edited sonic and density logs.Alsosonic and density log data were calibrated for 3 wells (EGB- 008, 009, and 010)so as to determine the mathematical relationship between the two. This relationship (Eq. 2) was used to determine either sonic or density log and it ensured that synthetics are generated in all the wells where either sonic or density log is missing. It has a regression coefficient of -0.6.

Sonic log = -0.512482 Density + 3.10016...Eq. 2

Two categories of Synthetic Seismogram (SS) were used for this study: SSI and SS2. The SS1 was derived using log data of wells: EGB008, 009, and 010 where both sonic and density logs were available. In the case of SS2, it was generated from the remaining 21 wells where either density or sonic log was not available.

The seismic model of the field was developed through the following processes:

Firstly, generation of a structural framework model of the field by digitization of the top structure map of B3000 reservoir to define the fault positions in the field. These faults served as key pillars in gridding the reservoirs into geocellular blocks of 50 x 50m each. A total of 23,760 grids were created over an area of 59.4 km^2.

Secondly, development of a stratigraphic model accomplished using the make Horizon processes in the petrel software. The various reservoirs and zones interpreted during the well correlation of the field served as input data for the stratigraphic modelling.

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Thirdly, geostatistical analyses involving upscaling of data and variogram analysis. The logs were upscaled so as to fit in the model.

Variogram analysis was carried out in the logs and on the sampled data along the vertical and horizontal directions respectively. The relationship between the gamma logs and acoustic impedance were also determined using descriptive statistics.

RESULTS

Well Log Correlation

Analysis of the well logs indicates that the field generally penetrated two distinct Formations of the Niger Delta basin.

The upper part with low gamma rayand high resistivity values indicates fresh water sands of the Benin Formation while the lower part contains sand and shale interbeds characteristic of paralic Agbada Formation. The base of the Benin Formation is sharp marked by the first appearance of thick shale bed.

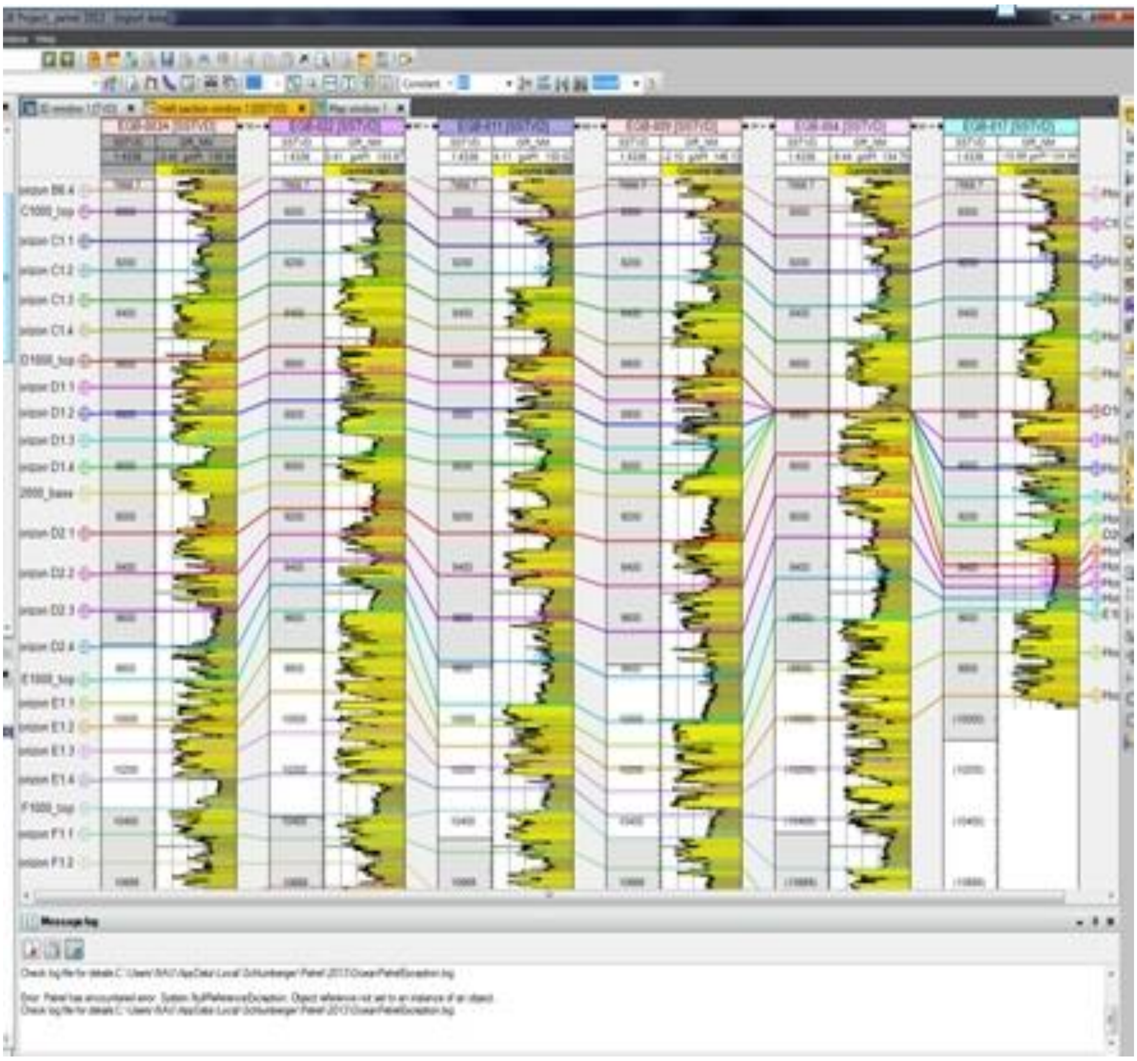

Fig. 2: An enlarged portion of the correlation panel

Seven distinct reservoirs labelled as B3000, B6000, C1000, D1000, D2000, E1000 and F1000 and four reservoir zones were interpreted during the correlation of the field. The zones and depths of the reservoirs in EGB-001 are shown in Table 1.

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Table 1: Depth to the tops of major reservoirs and their zones in EGB-001

Well identifier	**Surface**	**MD(ft)**
EGB-001	Reservoir B3000_Top	6665
EGB-001	Zone B3.1	6833.41
EGB-001	Zone B3.2	7001.64
EGB-001	Zone B3.3	7169.58
EGB-001	Zone B3.4	7337.32
EGB-001	Reservoir B6000_Top	7505.00
EGB-001	Zone B6.1	7608.07
EGB-001	Zone B6.2	7711.16
EGB-001	Zone B6.3	7814.19
EGB-001	Zone B6.4	7917.13
EGB-001	Reservoir C1000_Top	8020.00
EGB-001	Zone C1.1	8157.56
EGB-001	Zone C1.2	8295.18
EGB-001	Zone C1.3	8432.82
EGB-001	Zone C1.4	8570.43
EGB-001	Reservoir D1000_Top	8708.00
EGB-001	Zone D1.1	8822.51
EGB-001	Zone D1.2	8936.96
EGB-001	Zone D1.3	9051.33
EGB-001	Zone D1.4	9165.66
EGB-001	Reservoir D2000 Top	9280.00
EGB-001	Zone D2.1	9423.95
EGB-001	Zone D2.2	9567.93
EGB-001	Zone D2.3	9711.95
EGB-001	Zone D2.4	9855.98
EGB-001	Reservoir E1000_Top	10000.00
EGB-001	Zone E1.1	10090.02
EGB-001	Zone E1.2	10180.03
EGB-001	Zone E1.3	10270.03
EGB-001	Zone E1.4	10360.02
EGB-001	Reservoir F1100_Top	10450.00
EGB-001	Zone F1.1	10557.61
EGB-001	Zone F1.2	10665.22
EGB-001	Zone F1.3	10772.82
EGB-001	Zone F1.4	10880.41

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Petrophysical Analysis

The calculated porosity and volume of shale for Egbem Field are presented in (Tables 2 and 3) and their distributions across the entire field have overall average of 24.82 and 18.67% respectively.

Table 2: Porosity distributions of the various reservoirs across Egbem Field

Well Name	B3000	B6000	C1000	D2000	D1000	E1000	F1000	Total	Average
EGB001	0.2541	0.2354	0.2331	0.2134	0.2801	0.271	0.2502	1.7373	0.2481
EGB002	0.2165	0.2114	0.2345	0.2234	0.1955	0.2167	0.2114	1.5094	0.2156
EGB003	0.2356	0.2461	0.2257	0.2859	0.2112	0.2845	0.2458	0.7415	0.1947
EGB004	0.2156	0.2312	0.2716	0.2879	0.2951	0.2726	0.2516	1.3632	0.2731
EGB005	0.2983	0.2768	0.2765	0.3109	0.2925	0.3001	-	1.7551	0.2925
EGB006	0.2688	0.2998	0.2933	0.2904	0.2401	0.2933	-	1.6857	0.2810
EGB007	0.2456	0.2674	0.23019	0.2874	0.1985	0.2145	0.2789	1.7225	0.2461
EGB008	0.2378	0.2145	0.2547	0.2457	0.2378	-	-	1.1905	0.2381
EGB009	0.2453	0.2196	0.2755	0.296	0.2741	0.2602	0.3274	1.8981	0.2712
EGB010	0.2983	0.2561	0.2438	0.2456	0.2771	0.2347	0.2664	1.8220	0.2602
EGB011	0.2451	0.2549	0.25491	0.2132	0.2336	0.2556	0.2196	1.6769	0.2395
EGB012	0.2963	0.3141	0.1747	0.2422	0.1992	0.2217	-	1.4482	0.2413
EGB013	0.3116	0.2648	0.2442	0.2468	0.2151	0.2385	-	1.5210	0.2535
EGB014	0.2548	0.2871	0.29831	0.24387	0.2369	0.2436	0.2457	1.8102	0.2586
EGB015	0.2396	0.255	0.2446	0.2623	0.2474	0.2213	0.2139	1.6841	0.2406
EGB016	0.2367	0.2981	0.1269	0.2081	0.1958	0.2453	-	1.3109	0.2185
EGB017	0.2561	0.2457	0.1789	0.2494	0.1731	0.2767	-	1.3799	0.2299
EGB018	0.2348	0.2317	0.2398	0.2561	0.214	0.2458	0.2912	1.7133	0.2447
EGB019	0.3168	0.2628	0.2564	0.2941	0.2493	0.2687	0.2456	1.8937	0.2705
EGB020	0.2321	0.2769	0.244	0.2443	0.228	0.2448	-	1.4701	0.245
EGB021	0.2787	0.252	0.2406	0.254	0.2157	0.2350	0.1986	1.6746	0.2392
EGB022	0.2962	0.251	0.2383	0.2527	0.2007	0.2233	0.2026	1.6648	0.2378
EGB023	0.2365	0.2465	0.2447	0.2531	0.2378	0.2141	0.2075	1.6402	0.2343

EGB024	0.2387	0.2874	0.2387	0.2351	0.1985	0.2381	0.2851	0.7217	0.2459
Total	6.1899	5.97500	6.0639	6.1419	5.5471	5.7201	5.6966	37.5913	5.9577
Average	0.2579	0.259782	0.2527	0.2559	0.2311	0.2487	0.3351	1.5663	**0.2482**

Table 3: Volume of shale distribution of the various reservoirs across Egbem Field

S/N	Well Name	B3000	B6000	C1000	D1000	D2000	E1000	F1000	Total	Average
1	EGB001	0.2101	0.21	0.2121	0.1122	0.2109	0.1214	0.3661	1.452	0.2074
2	EGB002	0.2324	0.2123	0.1987	0.1106	0.2541	0.1621	0.2771	1.4473	0.2067
3	EGB003	0.1265	0.2136	0.2215	0.1382	0.1351	0.2169	0.2256	1.2774	0.1824
4	EGB004	0.2131	0.1011	0.1367	0.1013	0.2091	0.1319	0.2123	1.1055	0.1579
5	EGB005	0.2123	0.2012	0.1478	0.2127	0.1323	0.1601	-	1.0664	0.1777
6	EGB006	0.1511	0.1464	0.1012	0.2001	0.3007	0.1201	-	1.0196	0.1699
7	EGB007	0.1362	0.1524	0.2213	0.1278	0.1117	0.1651	0.2311	1.1456	0.1636
8	EGB008	0.2125	0.1408	0.1285	0.2203	0.2215	-	-	0.9236	0.1847
9	EGB009	0.2114	0.1823	0.1258	0.2125	0.2312	0.2018	0.2772	1.4422	0.206
10	EGB010	0.2007	0.1872	0.2173	0.2213	0.1014	0.1286	0.2281	1.2846	0.1835
11	EGB011	2.11E-01	0.1012	0.2132	0.2125	0.1983	0.2011	0.2131	1.3505	0.1929
12	EGB012	0.2121	0.2125	0.1742	0.2111	0.1362	0.1315	-	1.0776	0.1796
13	EGB013	0.2156	0.1267	0.2214	0.1673	0.3199	0.1754	-	1.2263	0.2043
14	EGB014	0.1234	0.2155	0.2001	0.2007	0.2218	0.2001	0.2611	1.4227	0.2032
15	EGB015	0.1167	0.2101	0.1118	0.2101	0.2868	0.0006	0.3979	1.334	0.1905
16	EGB016	0.2571	0.1643	0.2112	0.1601	0.2917	0.1442	-	1.2286	0.2047
17	EGB017	0.2398	0.2121	0.1214	0.2416	0.1122	0.1307	-	1.0578	0.1763
18	EGB018	0.1434	0.2123	0.2154	0.2001	2.92E-01	1.00E-04	2.85E-01	1.3483	0.1926
19	EGB019	0.1474	0.1213	0.1207	0.1703	1.18E-01	1.88E-01	2.60E-01	1.1259	0.1608
20	EGB020	0.2013	0.1134	0.2111	0.1899	0	0	-	1.0354	0.1725
21	EGB021	0.1357	0.2001	0.2212	0.1558	0.3001	0.1914	0.2608	1.4651	0.2093

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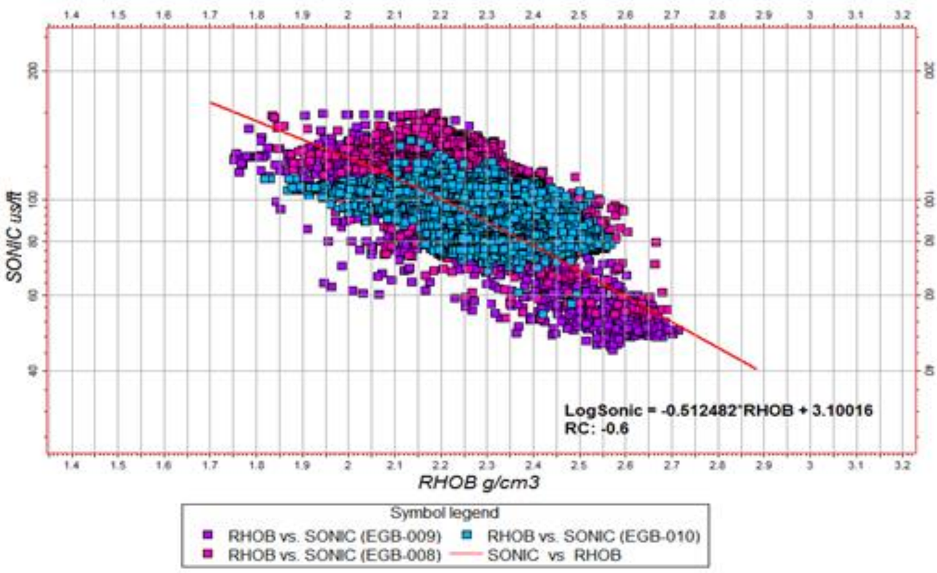
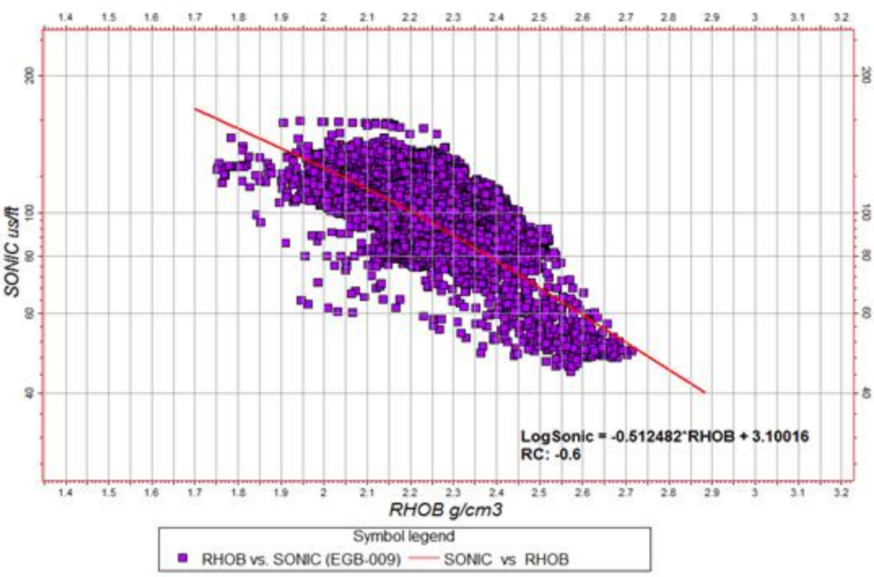
22	EGB022	0.1086	0.1211	0.2001	0.1629	0.2981	0.2015	0.2912	1.3835	0.1976
23	EGB023	0.0101	0.1434	0.1556	0.1735	0.3378	0.2001	0.2757	1.2962	0.1851
24	EGB024	0.1145	0.1356	0.2121	0.1782	0.2219	0.2011	0.1262	1.1896	0.1699
	Total	4.1431	4.0381	4.3004	4.2911	5.3702	3.3743	4.1886	29.705	4.4801
	Average	0.1726	0.1682	0.1791	0.1787	0.2237	0.1467	0.2617	1.2377	0.1867

Result of Synthetic Seismogram Generation

The result of sonic to density log calibration for three wells; EGB008, 009, and 010 is shown in Figure 3a. To validate this result, the log data of well EGB009 was used for calibration (Figure 3b).





The modelled wavelet profile used in the convolution process showed a zero-phase shift and normal polarity wavelet. The wavelet spectrum has a dominant frequency of about 30 Hz. This was convolved with the reflection coefficient (RC) data to produce synthetic seismograms for wells EGB008, EGB009 and EGB010 (Fig. 5). Radial synthetic seismographs were also generated at all the available wells in the field.

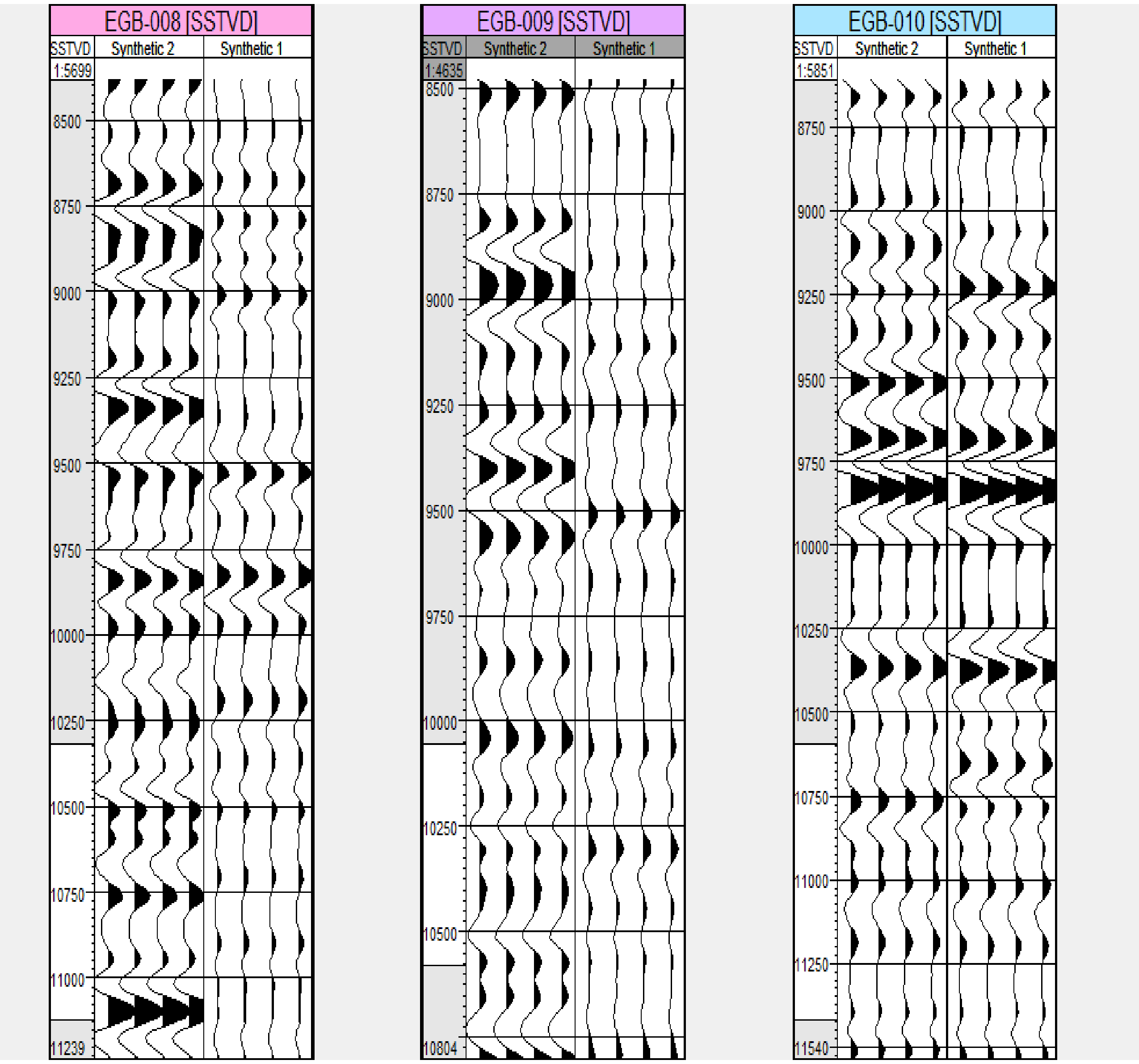


Fig. 5: Synthetic seismogram of some wells

Result of Seismic Model

The generated radial synthetics were used to match the synthetic of the log data which resulted in the generation of synthetic seismic at all the wells using gamma ray and acoustic impedance. Figures 6 and 7 showed the well-to-seismic match.

The very good match between the acoustic impedance and the gamma ray (Figure 7) became the basis for estimating acoustic impedance at wells without density or sonic logs. To substantiate this result, neural network was used to estimate acoustic impedance at well points and the results were also superimposed on the calculated acoustic impedance.

This superposition showed a reasonable match between the two as shown in Figure 7. This figure shows estimated acoustic impedance in red colour and the calculated impedance from log data in black colour.

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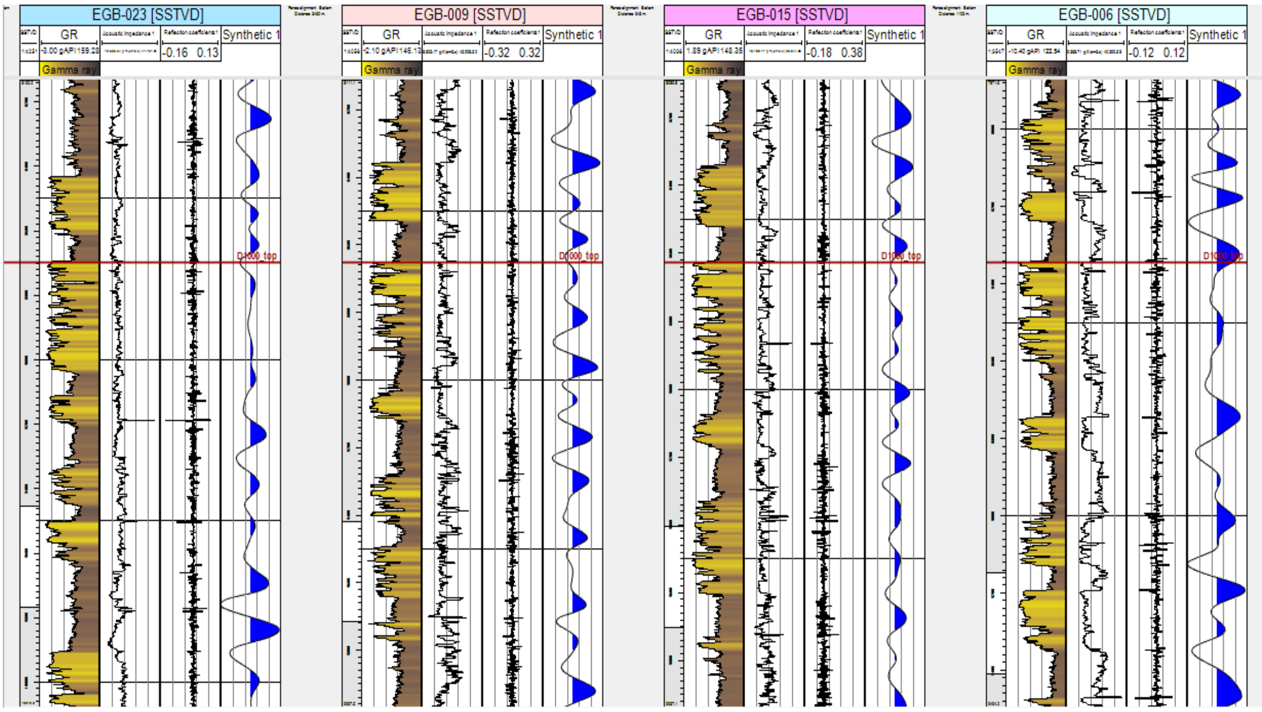

Fig. 6: Synthetic seismogram at some selected wells

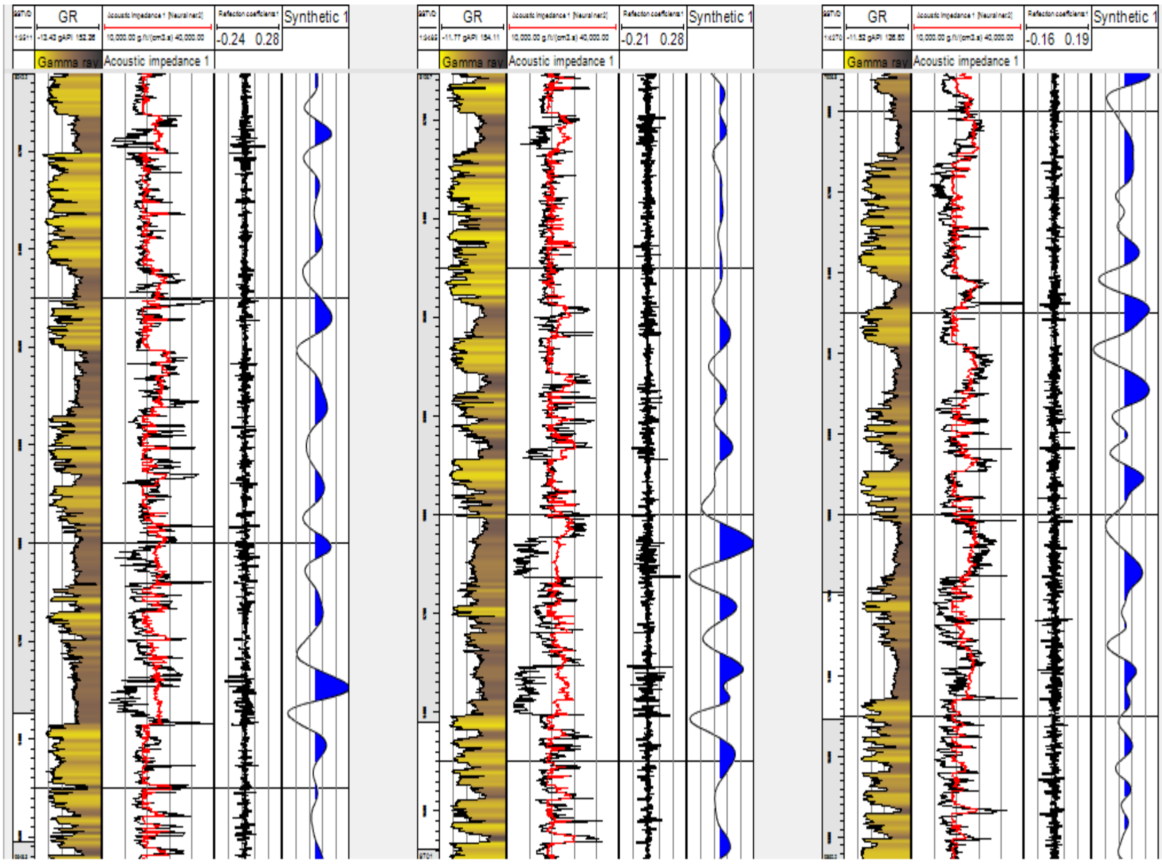

Fig. 7: Estimated acoustic impedance (red colour) superimposed on logcalculated Acoustic Impedance (black colour) for EGB008, 009 and 010 Wells

In order to define the stratigraphy of the field using the available log data, an average thickness of one unit of wiggle i.e. a wavelet in the synthetic seismogram was used as one unit thickness of resolvable unit of rock and the result is shown in Figure 8. Here, the acoustic impedance (red colour) and reflection coefficient (light green colour) were upscaled to test this resolution. This figure showed a reasonable match between stratigraphy defined by the two quantities.

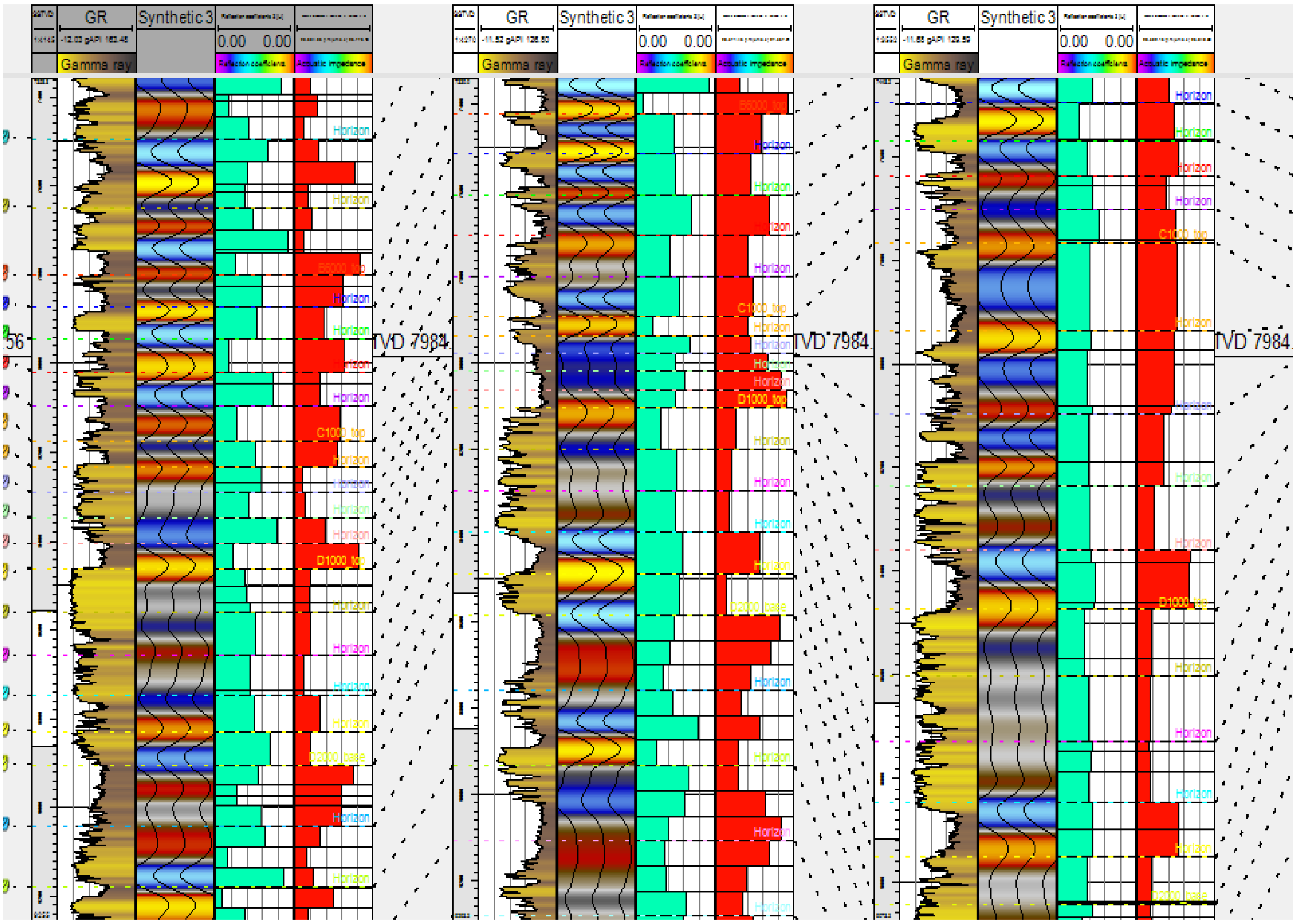

Fig. 8: Internal stratigraphy of Egbem Field defined using one unit of wiggle in the synthetic seismogram for EGB008, 009 and 010

Dimensional Models of Egbem Field

Facies Model

Acoustic impedance values generated were used to classify facies across the entire field. Four classes of facies were established using various peaks and troughs in the facies distribution, namely 1, 2, 3 and 4 corresponding to sand, shaley sand, sandy shale and shale respectively (Figure 9). The acoustic impedance values increase from class 1; the lowest acoustic impedance value to class 4, the highest acoustic impedance value. From this result, the highest acoustic impedance value was inferred to be shale (class 4) while the lowest acoustic impedance value was inferred to be sand (class 1). This classification formed the basis for construction of the final 3-D facies model of the field (Figure 10).

This model showed that the sand and shaley sand facies are concentrated at the central part of the field while the shale and sandy shale facies are concentrated at the fringes of the field (Fig. 10).

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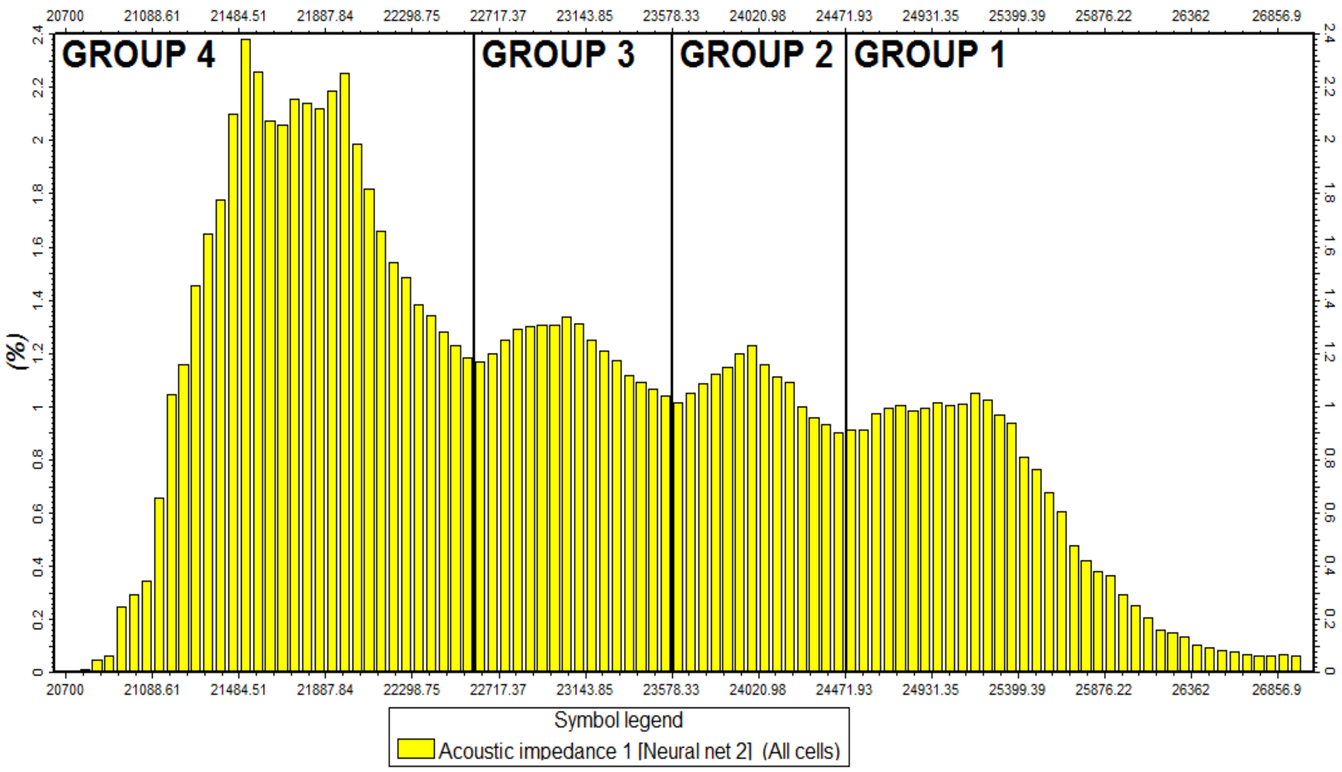

Fig. 9: The four classes of acoustic impedance used in facie model

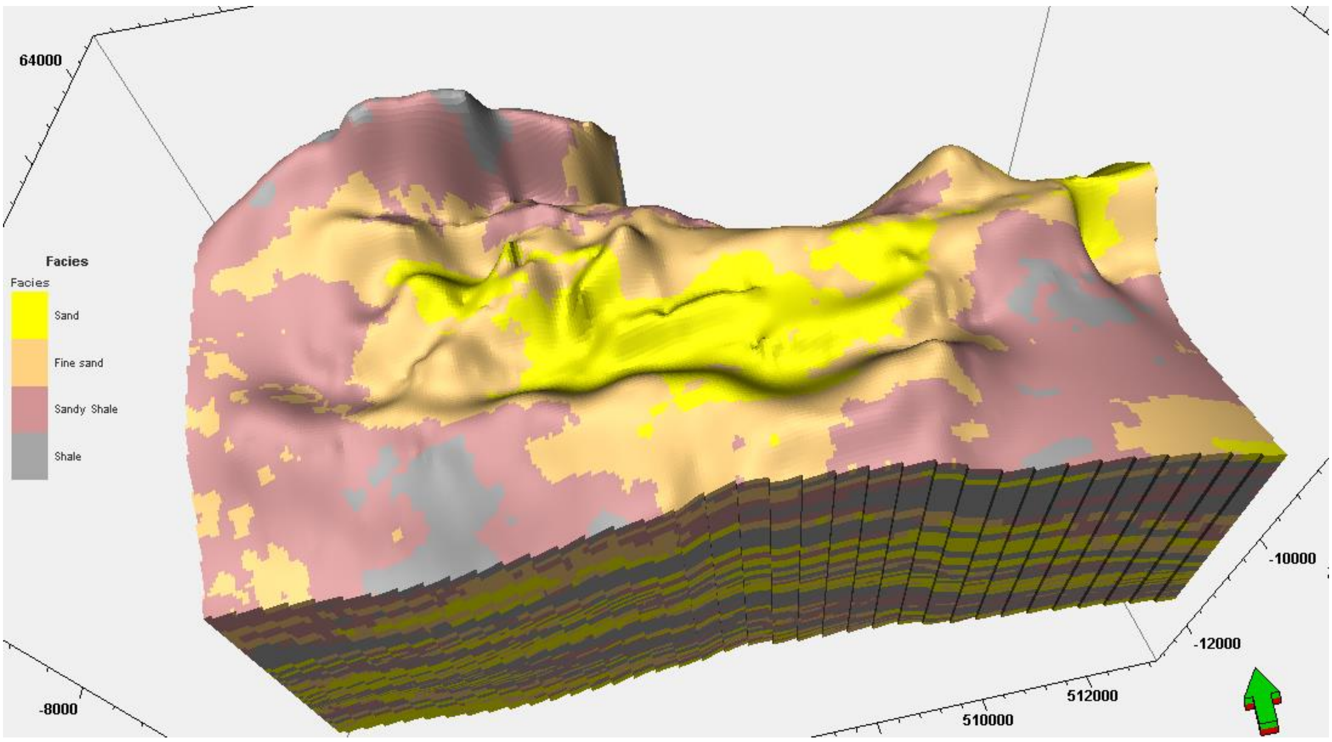

Fig. 10: Facie Model of Egbem Field

Porosity Model of Egbem Field

The model was built from porosities of log data and those determined from geostatistical analyses shown in Figure 11.

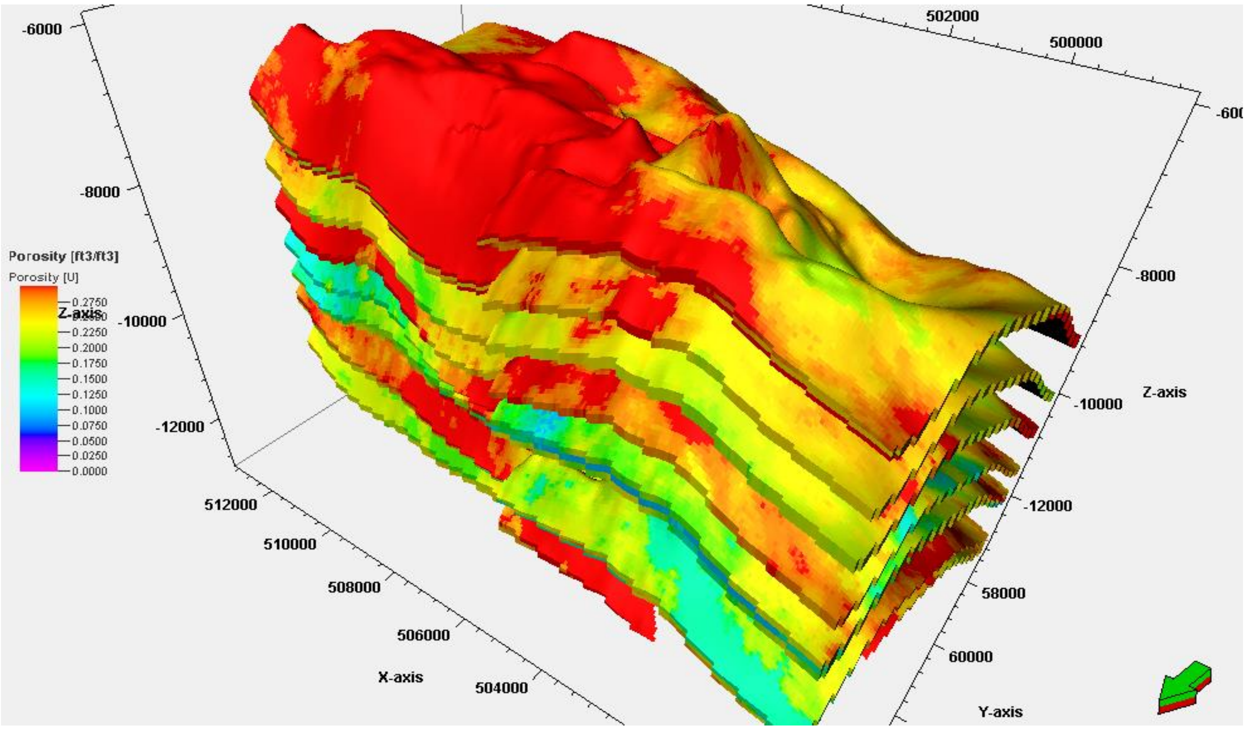

Figure 11: Porosity model of Egbem Field

Seismic Model of Egbem Field

The final 3D seismic model of the entire Egbem field is shown in Figure 12. This same figure is flattened on stratigraphy (Figure 13). Careful examination of these two figures shows a distinct similarity between them.

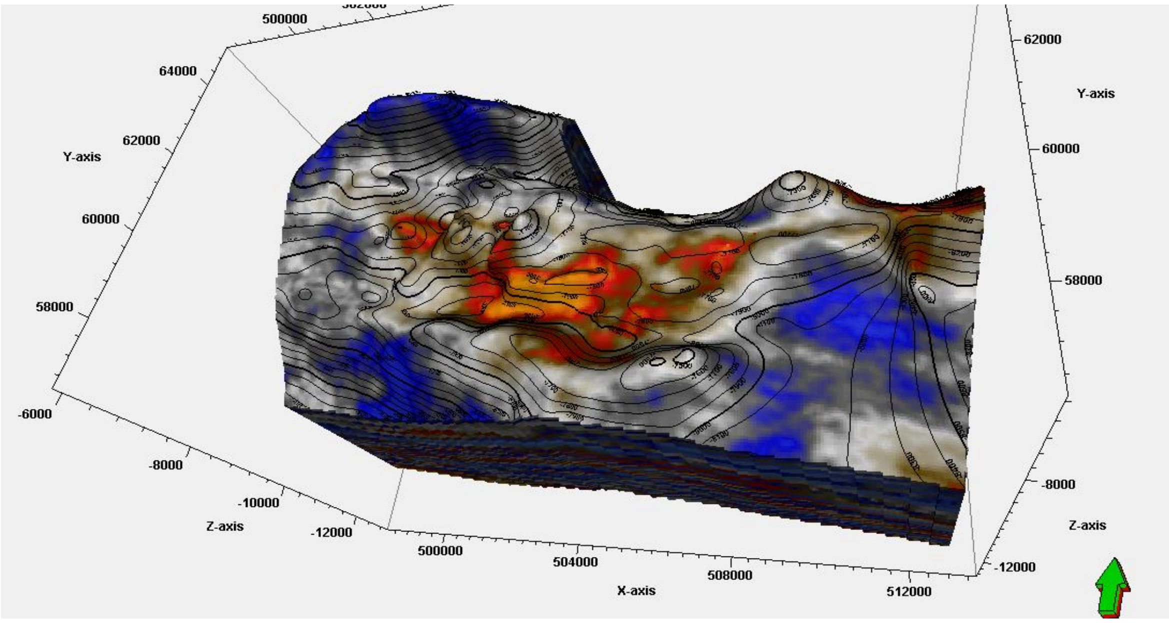

Fig. 12: Seismic model of Egbem Field

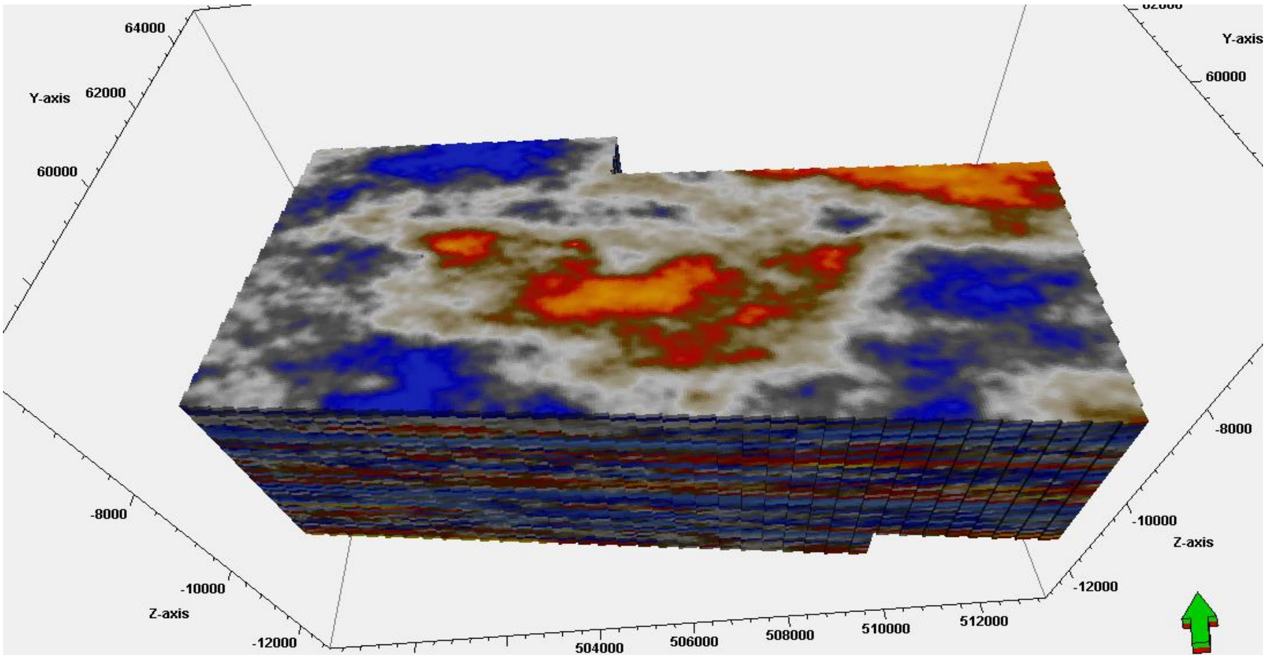

Fig. 13: Seismic model of Egbem Field flatten on stratigraphy

DISCUSSION

Three-dimensional seismic model of Egbem Field has been constructed using log data from twenty four wells. The application of geostatistical analyses extrapolated and interpolated these log data to cover the entire field. These procedures honour the original log data. In other to validate this result, steps were taken to correlate the original data with that produced from the 3D models as follow:

Porosity Distribution

The porosity as determined using the log data was plotted alongside those at the same well locations from the modelled porosity result (Fig. 4.1). This figure shows that the two porosity distributions are closely related as indicated by their line graphs. However, their spatial distributions showed minor variation which can hinder the flow and estimation of the overall fluid found in the reservoirs of Egbem Field.

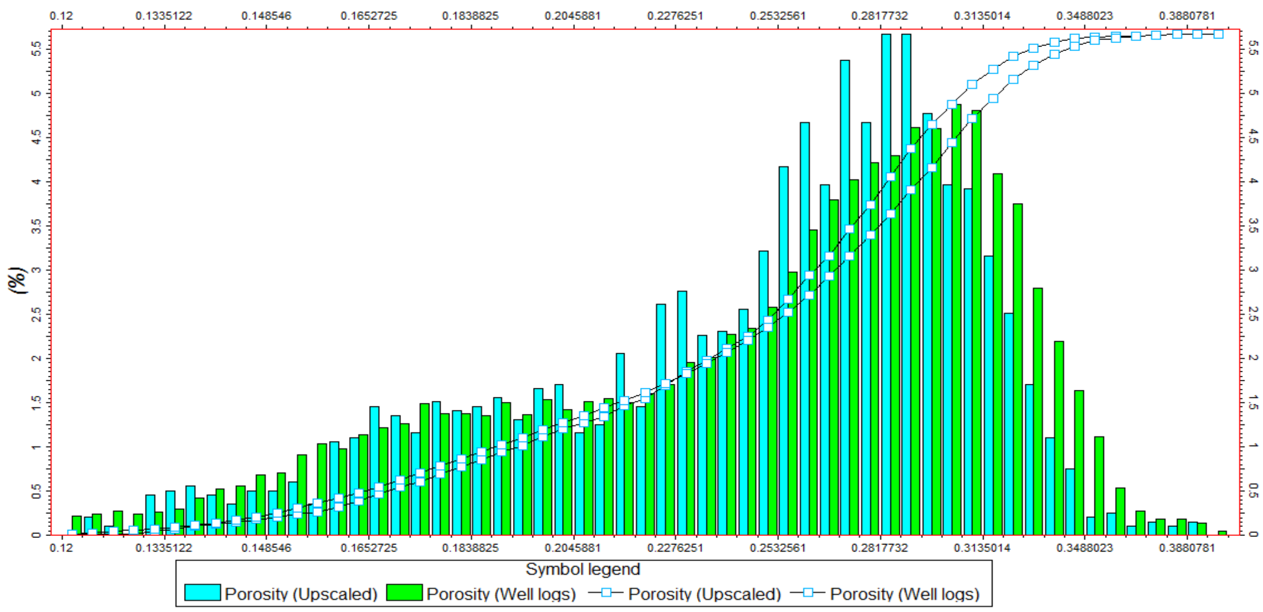

Fig 4.1: Porosity distribution of the original log data and that of modeled sample data

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To add credence to this relationship, some of the original log porosities were compared with upscaled sample data, again they showed very close relationship (Fig. 4.2). The resemblance between these porosities is clearly shown in this figure.

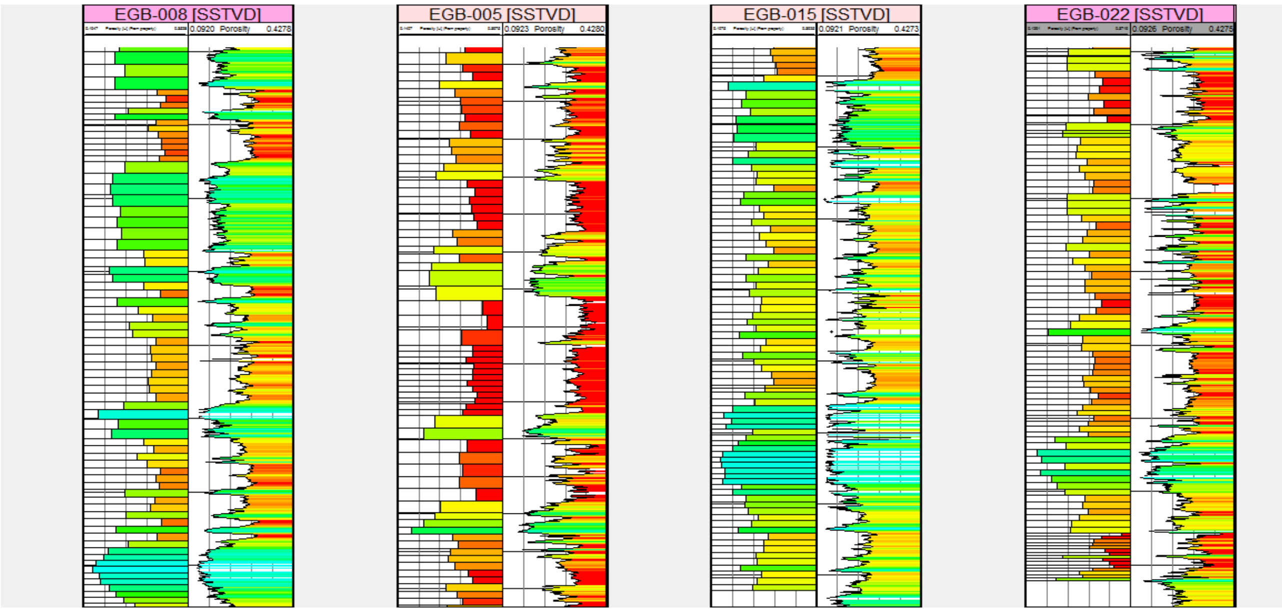

Fig. 4.2: Comparing log porosities at some selected wells

Relationship between Predicted Facies and Inferred Lithologies from Gamma Ray

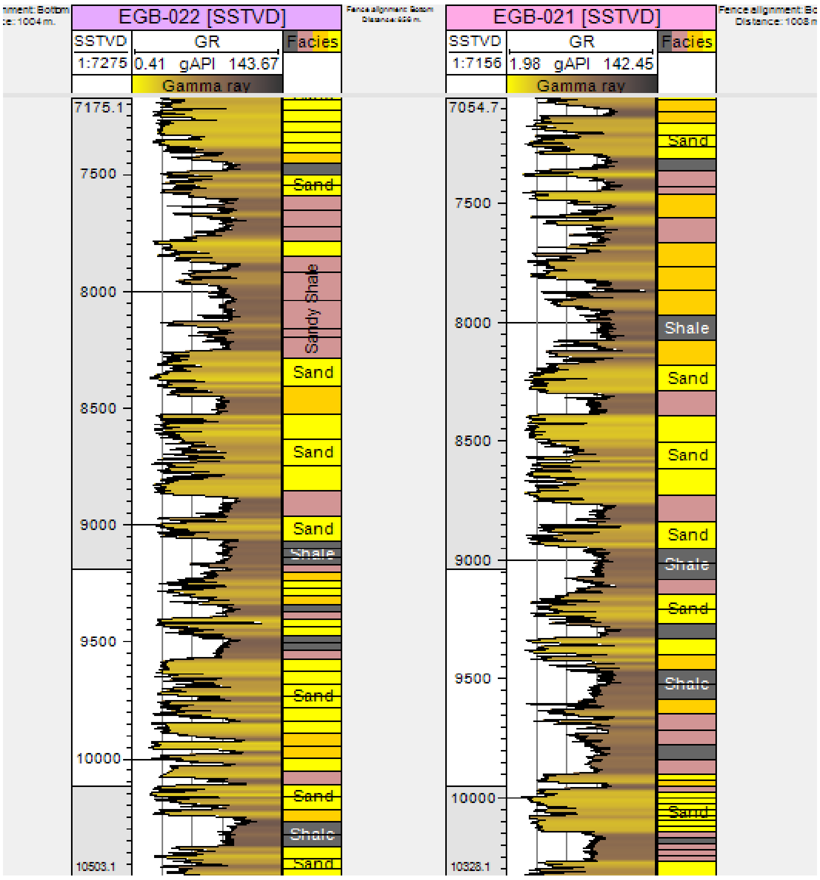

Fig 4.3: Acoustic impedance at some wells using gamma ray as training material

Predicted facies were compared with lithologies inferred from some selected wells to understand their relationship (Figure 4.3). The figure shows a close relationship between the facies inferred from the research analyses (left) and the inferred gamma ray lithologies (right). There is good relationship between the predicted facie using acoustic impedance and the gamma ray lithologies (Figure 4.3).

CONCLUSION

The seismic model of Egbem Field, Niger Delta, Nigeria has been generated using geophysical well logs in the prediction of inter-well petrophysical properties.

The result of the petrophysical analysis showed that the porosity of the field varies between 12.69 – 32.74% with an average porosity of 24.8% while the average value of the volume of shale is 19.9%. The result of the acoustic impedance classification reveals four classes of facies namely: shale, sandy shale, shaley sand and sand. The facie model indicates that sand which is a good reservoir is concentrated at the central part of the field. The result of synthetic seismic generation shows a very good match between acoustic impedance and lithology. Finally, Three-dimensional seismic model of Egbem Field has been constructed using log data from twenty four wells. The application of geostatistical analyses extrapolated and interpolated these log data to cover the entire field. These procedures honour the original log data as correlation and neural networks were used to validate the results obtained from the analyses.

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