Predicting Zones of Overpressure in Coastal Swamp Depobelt of Niger Delta Nigeria, Using Well-Log and Seismic Data

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ABSTRACT: *Sixty overpressure zones were established in eighteen wells in the EKON and IDUMA fields. The predicted zones gave insight into the determination of overpressure origin and mechanism within the Coastal swamp Depobelt. Results show that increased bulk density observed from the sand sequences at greater depths indicated compaction. Faults and horizons mapped revealed the segregation of wells with similar hydrocarbon contacts into various pressure compartments. This indicated overpressure zones. Also, the good ratings of petrophysical properties within the reservoir units were pointers to overpressure regions. Over pressured zones predicted from the Eaton sonic transit time model tallied with the outcome of results obtained using the seismic method. In addition, the reservoir tops conformed to the upper limits of overpressure while their bases coincided with the lower limits of overpressure. Results obtained from this study, confirmed compaction disequilibrium as the primary mechanism of over-pressure while tectonism and hydrocarbon gradient were inferred as secondary mechanisms.*

Keywords: *Compaction, porosity, velocity, overpressure, pressure compartments, Niger Delta, Nigeria.*

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INTRODUCTION

A formation is said to be overpressured when an abnormally high pore pressure greater than the hydrostatic pressure occurs at a given depth, Dickinson (1953). Overpressure is very key as it occurs worldwide in sedimentary basins where hydrocarbon is exploited and produced. Hence it is important to understand and predict the regional distribution of overpressure accurately in the Coastal Swamp Depobelt of the Niger Delta Basin, in other to minimize associated risks, ensure the safety of lives and properties, and enable adequate field development plan that would lead to the optimization of assets.

A review of previous works shows that various authors ; Olubunmi (1990); Chopra and Huffman (2006); Osinowo et al (2007); Steve O'Connor et a.l (2011); Uko et al (2013); Olatunbosun Alao et al. (2014); Ugwu (2015); Udo et al. (2015); Ude et al. (2017); Nwankwo and Kalu (2016) have worked extensively on overpressure studies in the Niger Delta Basin, however theses studies were carried out on a local scale.

Olubunmi (1990); Ugwu (2015); Nwankwo and Kalu (2016**)** predicted overpressure zones in the Western Niger Delta with resistivity and the sonic log.They showed that with increasing depth, over pressured zones correspond to the intervals of anomalous increase in resistivity and sonic porosity.

Also**,** Steve O'Connor et al (2011) used wireline logs and direct pressures measurement to evaluate overpressure zones in the Deep Water and Ultra-Deep Water offshore areas of the Niger Delta Basin. He concluded that increased porosity and pressure gradient correspond to the top of the overpressure zone.

Uko et al (2013); and Udo, et al (2015); used interval transit time from sonic log and acoustic impedance to identify the tops of over pressured zones in the North

West and South-South part of the Niger Delta respectively. They noted that the tops of overpressure zones align with transition between the normal and deviated porosity.

Other researchers like; Chopra and Huffman (2006); Osinowo et al (2007); Alao et al. (2014); and Ude et al. (2017) analyzed interval velocity from seismic inversion and sonic log in the western Niger Delta, Afam and Fabi field respectively. They proposed that overpressure zones correspond to a decrease in interval velocity.

As a way to improved overpressure zone prediction, this research is focused on the regional and qualitative prediction of overpressure zones with well log and seismic data in EKON and IDUMA field. This involved correlation of the various reservoirs top and base units encountered by the wells. The structural seismic interpretation enabled proper definition of the geologic structural style and fault/pressure compartment. It also aided in generating interval velocities. In addition, the petrophysical properties estimated within the reservoir units provided a platform for anticipating the limits of overpressure.

Again, compaction curves obtained from the Eaton sonic transit time model enabled overpressure zone prediction from well data; while Interval velocities and acoustic impedance used in the seismic predictions improved the quality of the well logging methods.

Mechanisms of overpressure were deduced from both the well logging and seismic methods. Results obtained from both fields were compared for similarity and thus used to infer other prospective localities.

It is important to note that overpressure prediction in previous studies, were limited locally. However, the regional prediction of overpressure zones employed in this research enabled a proper definition of the origin and current mechanism of overpressure in the study area; this was used to infer prospects in other localities

LOCATION OF STUDY AREA

EKON and IDUMA fields are both located onshore within the south-eastern part of the Coastal Swamp Depobelt, Niger Delta (Figure1). Eighteen (18) wells were studied in these fields.

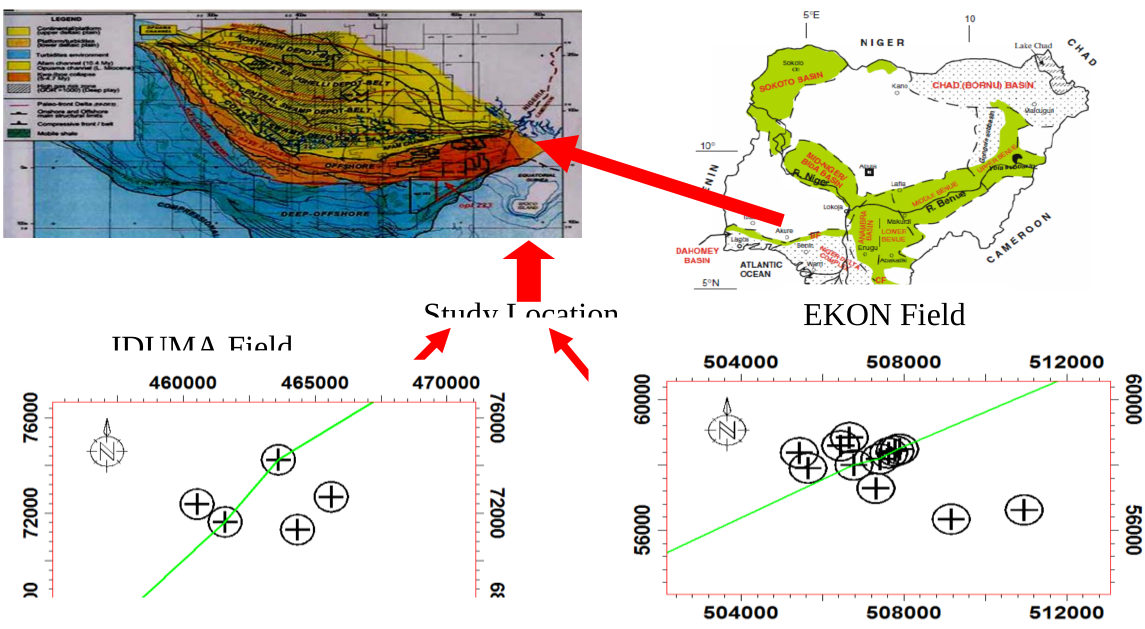

Figure 1: Location map of the Niger Delta Basin showing the study area Obaje (2009); Nwozor et al (2013).

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GEOLOGIC SETTING

Various workers have explained the evolution of the Niger Delta basin. (Knox and Omatsola, (1978); Whiteman, (1982), Weber and Daukoru, (1975); Mascle et al, (1973); Oomkens, (1974); Murat, (1972); Short and Stauble, (1967); Hospers, (1965, 1971); Allen, (1964, 1965).

The Eocene to Recent regressive depositional cycle left behind a huge deltaic stratigraphic assemblage, about 8 kilometers thick at the centre of the delta, Hospers (1965, 1971), Short and Stuable (1967). Omatsola (1978) believed that the prism of sediments overlying the crust in the delta developed a maximum thickness of 12 kilometers at the central part of the delta. The formation of the present day Niger Delta started during the Early Paleocene and it resulted from the build-up of fine grained sediments eroded and transported by the River Niger and its tributaries. Short and Stauble (1967) described this thick succession of sediments as consisting of three lithostratigraphic units namely the Akata, the Agbada and the Benin Formations, (Table1).

Table 1 Geologic Formations in the Niger Delta area (after Short and Stauble 1967)

Subsurface			Surface Outcrops		
Youngest Known Age		**Oldest Known Age**	**Youngest Known Age**		**Oldest Known Age**
Recent	Benin Fm	Oligocene	Polio/ Pleistocene	Benin Fm	Miocene
Recent	Agbada Fm	Eocene	Miocene Eocene	Ogwashi – Asaba Fm Ameki Fm	Oligocene Eocene
Recent	Akata Fm	Eocene	L. Eocene Paleocene	Imo Shale Fm Nsukka Fm	Paleocene Maestrichtian
Equivalent not known		Maestrichtian Campanian Camp/Maest.		Ajali Fm Mamu Fm Nkporo Fm	Maestrichtian Campanian Santonian
		Coniaciani Santonian Turonian Albian		Agwu Shale Eze-Aku Fm Asu River Group	Turonian Turonian Albian

Akata Formation: It is the basal unit of the delta (Avbovbo, 1978). It is Paleocene in age,

and as well the source rock of the delta (Weber and Daukoru, 1975; Ekweozor and Daukoru, 1984).The formation is composed predominantly of under compacted thick shale, lenses of sandstones, turbidity sands and a small amount of silt with 20% sand and 80% shale (Evamy *et al*, 1978). The formation has an estimated thickness of 7000m (Doust and Omatsola, 1990). Its lateral equivalent in the northeastern zone is the Imo Shale while in offshore areas it outcrops in diapirs (Avbovbo, 1978).

Agbada Formation: It overlies the Akata formation. It is Eocene in age, reservoir unit of the delta (Weber *et al*, 1978). The upper portion comprises sand with only minor shale interbeds while the lower portion comprises sand-shale intercalations; with the shale sequence forming the cap rock in the delta. The sequence has 60% sand and 40% shale (Evamy *et al*, 1978). Also, it has an estimated thickness of 3700m (Reijers, 1996). The lateral equivalent of the upper part of Agbada formation is the Ogwashi-Asaba Formation, which outcrops around Ogwashi and Asaba, in southern Nigeria (Doust and Omatsola, 1990), while the Ameki formation is the lateral equivalent of the lower part of the formation.

Benin Formation: It is Oligocene in age. It is the uppermost part of the unit and it overlies the Agbada Formation. It consists mostly of continental sands with 90% sand and 10% shale (Evamy *et al*, 1978**)**. The thickness of the formation is about 2100m at the central part. (Whiteman, 1982).

DATA

The research data were provided by the Shell Petroleum Development Company. They include well header, well deviation data, well logs, and three dimensional (3D) seismic data check shot, well picks.

METHODOLOGY

The methods adopted in this study include identification of key lithologic and reservoir units from gamma ray (GR), Resistivity (ILD) and spontaneous potential (SP) logs, well to seismic tie using check shot sonic (DT) and density (RHOB) logs. Faults were mapped on seismic as breaks in the continuity of reflections, while the horizions mapped were used in generating time map. Checkshots were inputed to the velocity equations to enable the conversion of time structural maps to depth. Petrophysical/reservoir quality analysis was carried out with well log data. Over pressured zones were predicted in wells by generating compaction curves obtained from the Eaton sonic transit time model while interval velocities and acoustic impedance were the basis of the seismic prediction. Overpressure mechanisms were deducted from the result of the study this enabled inferences of prospective localities.

RESULTS AND DISCUSSION

Well Correlation

Two dominant lithologies namely sand and shale were established in the EKON and IDUMA fields. They varied vertically and laterally across the study area. On the gamma ray log, the sand interval was coloured yellow whereas the interval coloured grey depicted

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the shale unit. Forty-five reservoir zones were correlated across thirteen EKON wells while fifteen was correlated across five IDUMA wells (Figure 2 and 3).

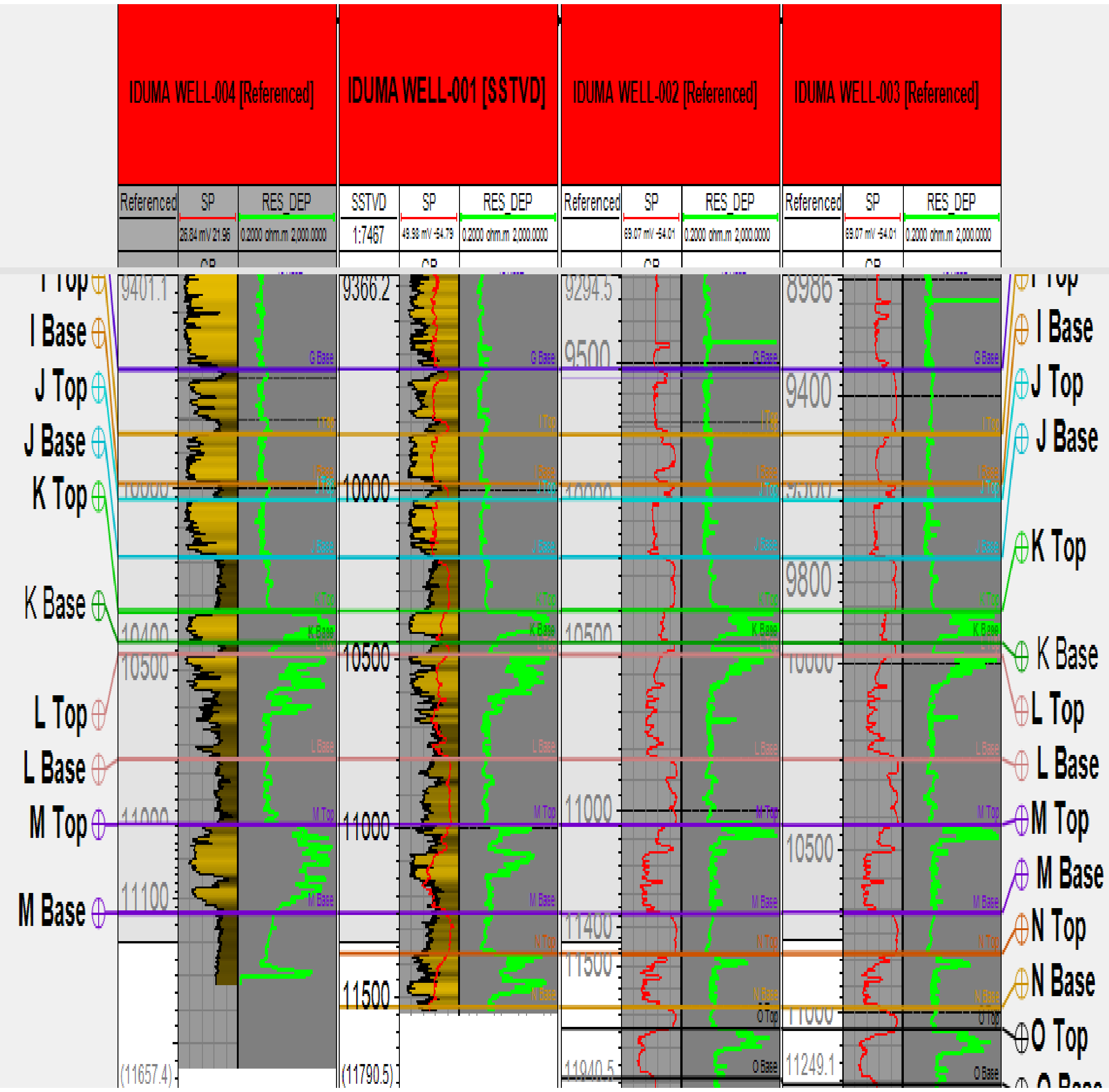

Figure 2: EKON Field Correlation in the East-West Direction

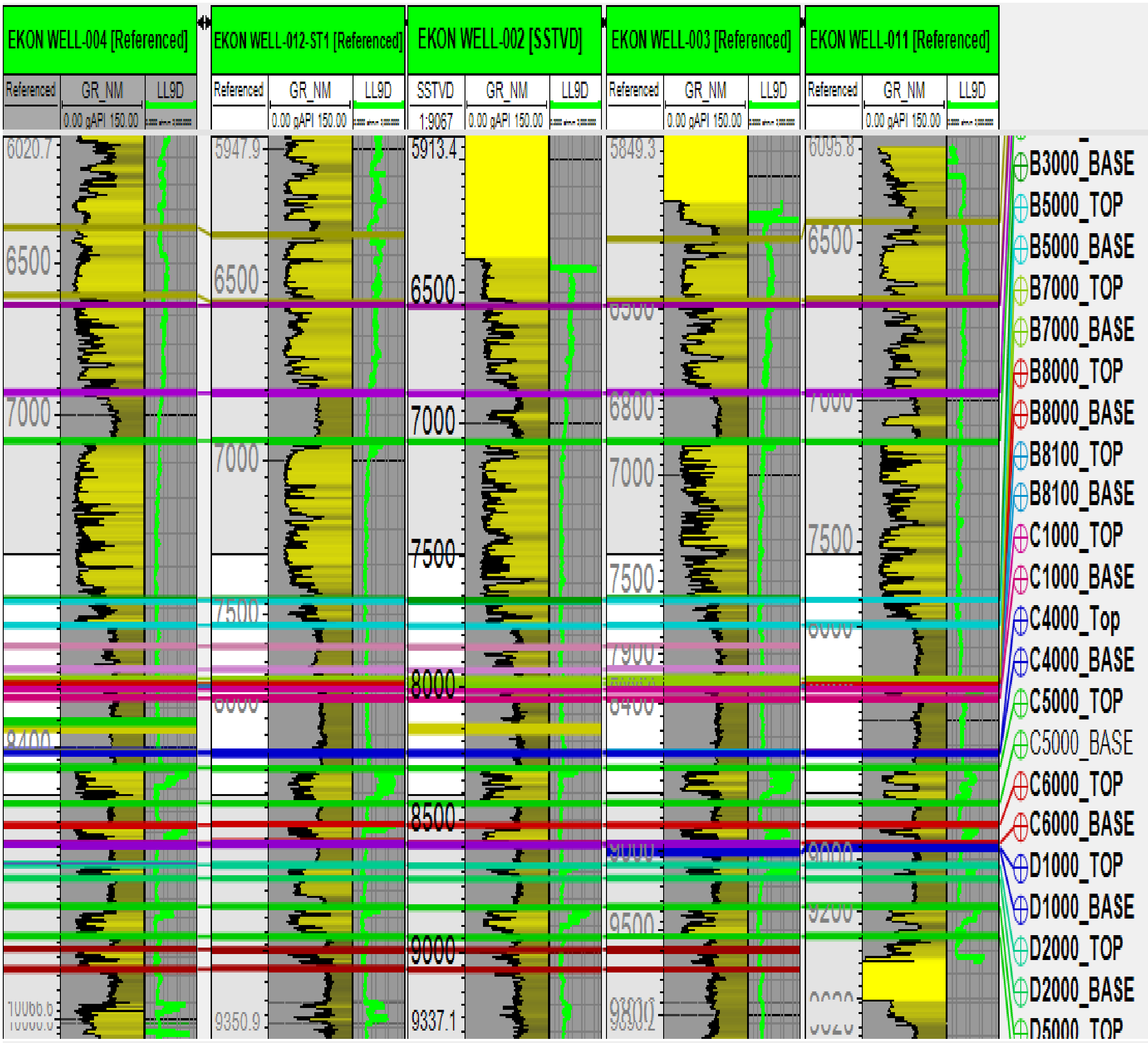

Figure 3: EKON Field Correlation in the East-West Direction

Well to Seismic Tie

Result showed that the reservoir sands encountered in fields were tied to trough. Thus a deflection of the wavelet to the left depicts the trough (coloured white) while a deflection to right represents the peak (coloured red). In EKON-001, the reflections in the well synthetic were stretched and squeezed by -10.33ms to match the reflection on the seismic section while a bulk-shift of 5ms was applied to matchIDUMA-001 synthetic, (Figure 4 to 7).

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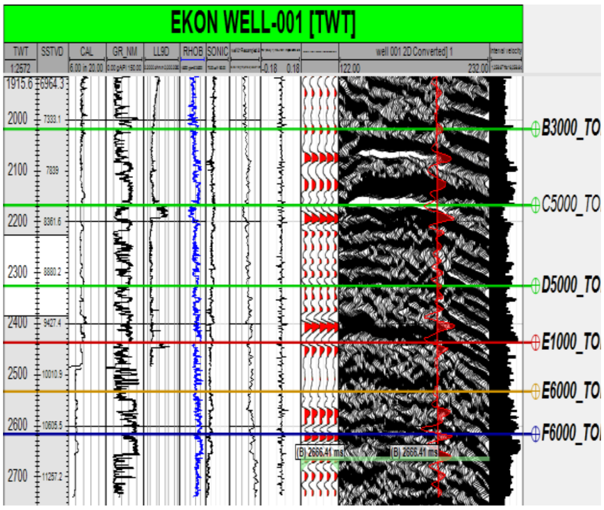

Figure 4: EKON-001 Well to Seismic Tie

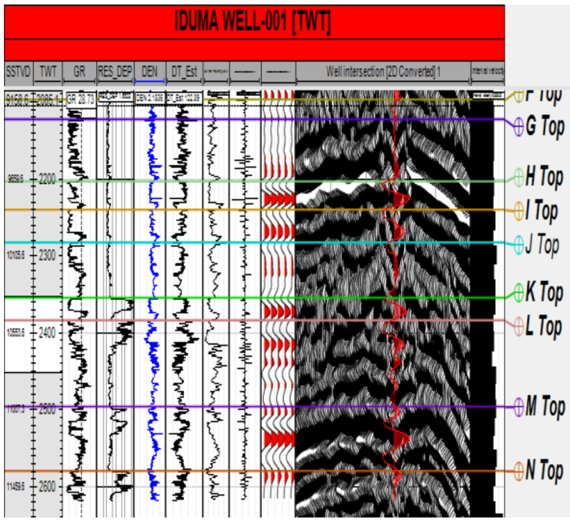

Figure 5: IDUMA-001 Well to Seismic Tie

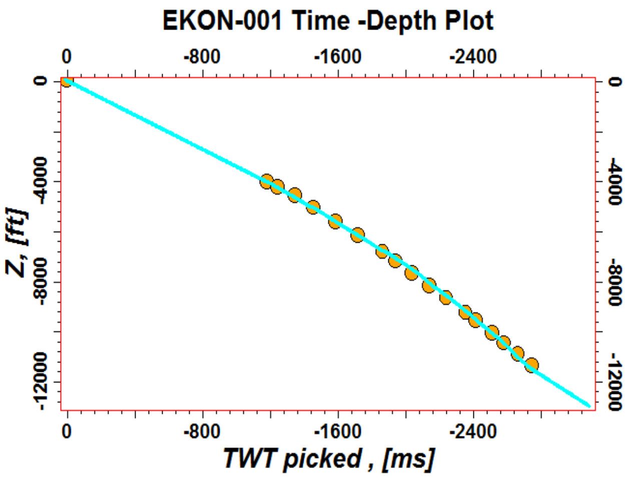

Figure 6: EKON-001Time depth plot Before and After Match

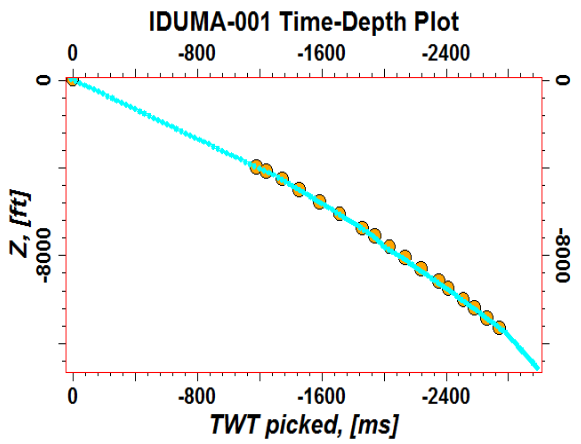

Figure7: IDUMA-001Time depth plot Before and After Match

Fault and Horizon Mapping

The fault and horizons mapping revealed series of complex faulting pattern such as growth faults, normal faults synthetic and, antithetic faults as well as collapse crest structures. Thirty-five faults with four pressure/fault compartments were established in the EKON field while thirty three were present in IDUMA field with five pressure/fault blocks (Fig. 8 to 11).

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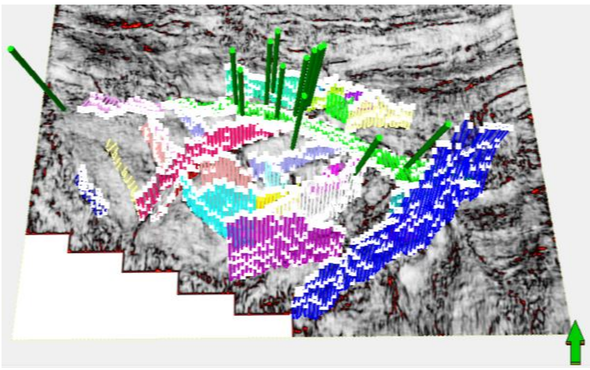

Figure 8: 3D View of EKON Fault Interpretation

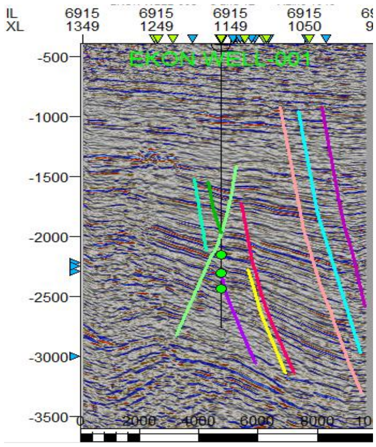

Figure 9: Interpreted EKON Faults Sticks

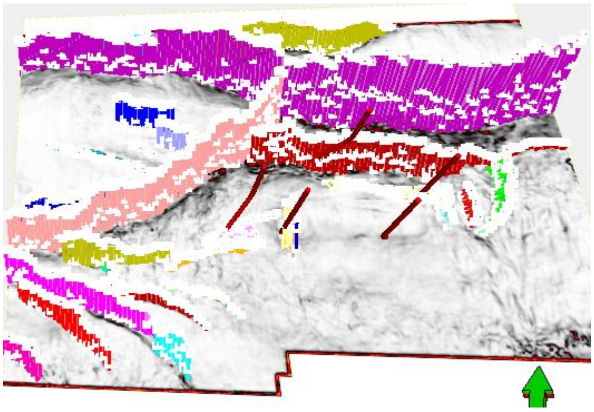

Figure 10: 3D View of EKON Fault Interpretation

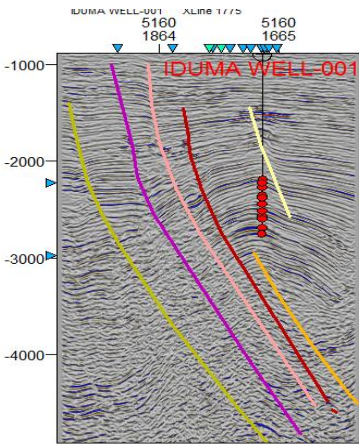

Figure 11: Interpreted EKON Faults Sticks

Petrophysical/Reservoir Quality Analysis

Petrophysical properties analyzed within the EKON and IDUMA reservoir units showed good rating for porosity, permeability and net to gross. (Table 2).

Table 2**:** Summary of Petrophysical/Reservoir Quality Analysis in EKON-001 and IDUMA-001 Wells

RESERVOIR	NTG	PHIT_D	K
IDUMA -001			
A Top	0.886	0.394	0.322
B Top	0.909	0.403	0.323
C Top	0.731	0.358	0.311
D Top	0.549	0.357	0.305
E Top	0.898	0.361	0.307
F Top	0.87	0.339	0.276
G Top	0.886	0.32	0.283
EKON-001			
B1000_TOP	0.821	0.341	1178.66
B2000_TOP	0.872	0.318	839.672
B3000_TOP	0.848	0.294	595.302
B8000_TOP	0.63	0.274	441.416
B8100_TOP	0.561	0.295	535.612
C1000_TOP	0.397	0.218	156.965
C3000_TOP	0.159	0.208	140.638
C4000_Top	0.542	0.309	754.062
C5000_TOP	0.819	0.352	1250.49
C6000_TOP	0.864	0.286	505.758
C8000_TOP	0.75	0.29	551.948
D2000_TOP	0.754	0.3	602.344
D5000_TOP	0.796	0.285	506.176
D7000_TOP	0.679	0.291	538.037
D9500_TOP	0.155	0.262	358.65
E1000_TOP	0.647	0.282	473.089
E2000_TOP	0.808	0.269	385.838
E3000_TOP	0.603	0.272	448.878
E4000_TOP	0.788	0.26	351.817
E4500_TOP	0.817	0.254	336.042
E5000_TOP	0.862	0.261	347.746
E6000_TOP	0.799	0.268	391.591
E8000_TOP	0.598	0.253	318.651

Overpressure Prediction

Over pressured zones predicted with well log data were quality checked with the seismic methods. The result of the analysis is shown below.

The compaction curve model obtained from the Eaton sonic transit time model, which requires porosity estimation, was the basis of the well logging method of overpressure prediction. Sonic transit time (DT), sonic (PHIT_S), and density (PHIT_D) porosity analyzed for nine (9) EKON wells and five (5) IDUMA all showed porosity decrease in normally pressured shale zones. However, they increased anomalously at every over pressured zone, deviating from the normal compaction trend. The results in (Figure 4 and 5) showed that the curve coloured yellow depicted the gamma ray (GR) log which differentiated the shale

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zones from the sand units. The resistivity (ILD) log was coloured green. It established the presences of hydrocarbon fluid in the wellbore which was represented by a deflection of the curve to the right. Hydrocarbon zones were observed to correspond to over pressured regions. The density (RHOB) log coloured deep blue showed an increase in bulk density in normally compacted zones. However, it decreased in over pressured regions. Also, the sonic transit time (DT) curve showed a decrease in transit time with increasing depth of compaction. While the sonic and density porosities coloured light blue and peach respectively showed porosity loss in normally compacted zones with an anomalous increase in over pressured regions.
Again, the plot of sonic transit time (DT) against depth as well as that of sonic (PHIT_S), and density (PHIT_D) porosities cross-plot, all showed an anomalous increase in sonic transit time and porosity in over pressured zones (Figure15 to 19).
seismic velocities, derived from well to seismic tie, second and third order polynomial velocity model as well as acoustic impedance, were analyzed for ten (10) EKON wells and five (5) IDUMA wells. Results showed that velocity (V) and acoustic impedance (AI) both increased with depth in normally pressured shale zones. However, at ever over pressured zones, they decrease anomalously shows. The results in (Figure 4) showed that the curve coloured red represented the acoustic impedance (AI), while the curved coloured white depicts velocity derived from sonic transit time. The velocities derived from well to seismic tie, second, and third order polynomial were coloured light blue, yellow and purple respectively, (Figure 12 to 27).

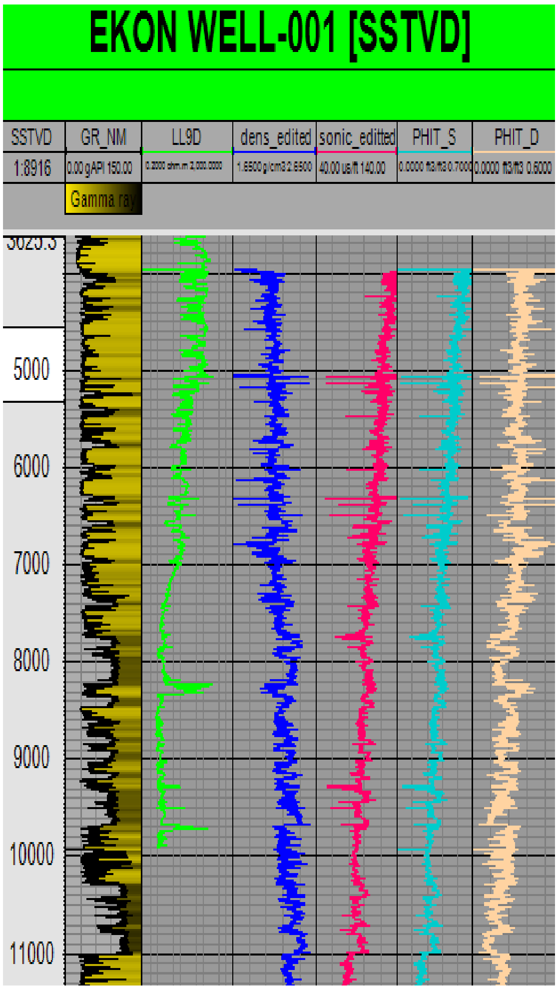

Figure 12: Overpressure prediction in EKON-001 (Well log Method)

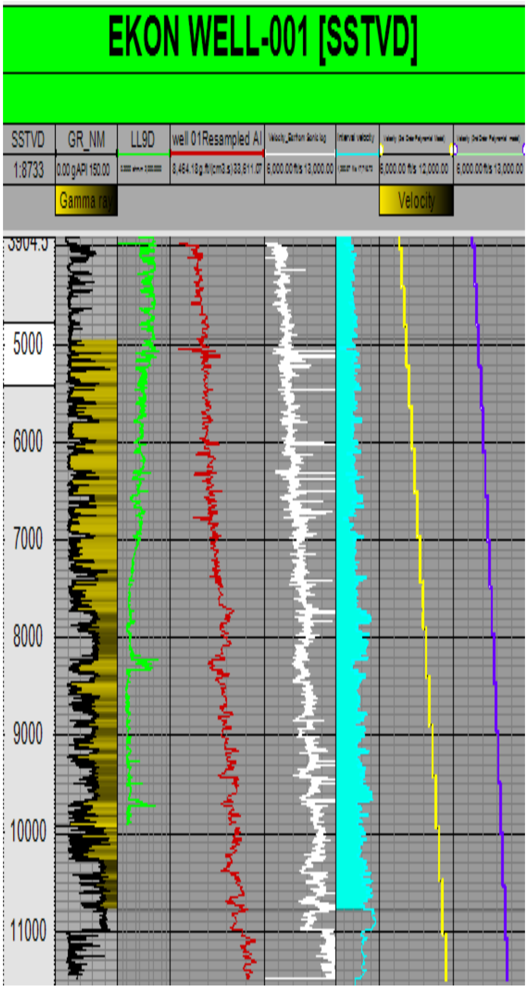

Figure 13: Overpressure prediction in EKON-001(Seismic Methods)

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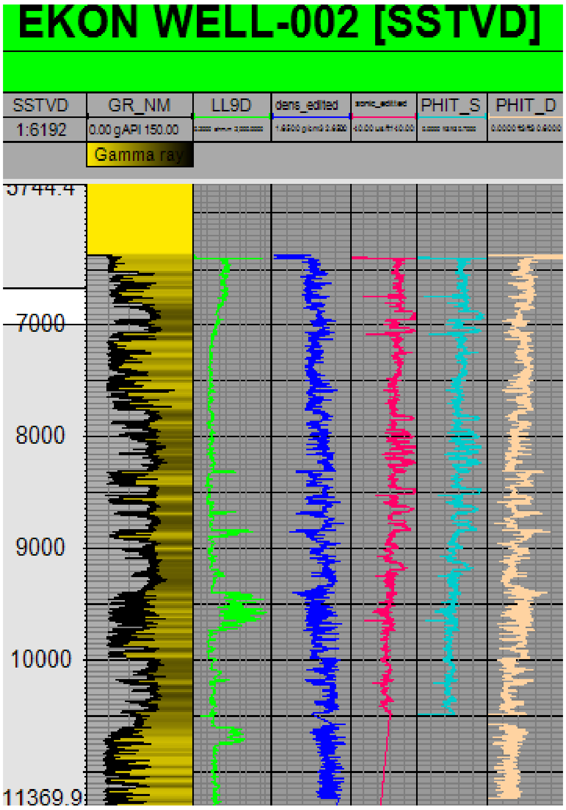


Figure 14: Overpressure prediction in EKON-002 (Well log Method)

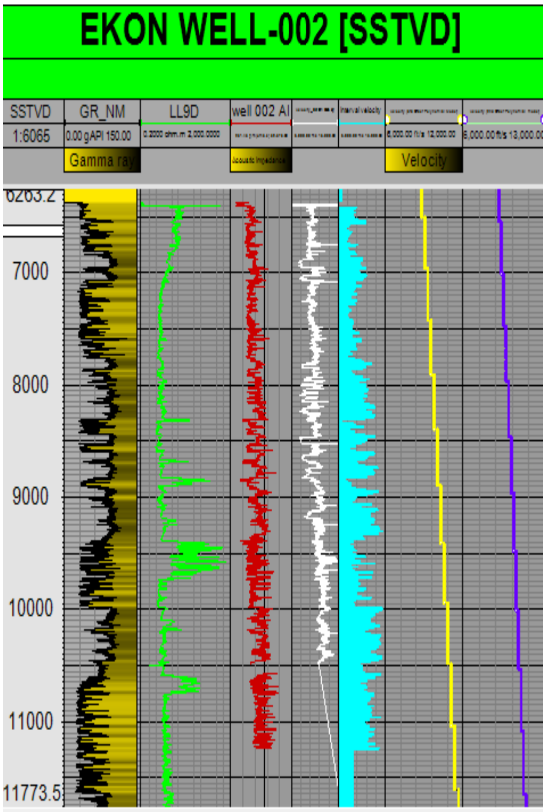
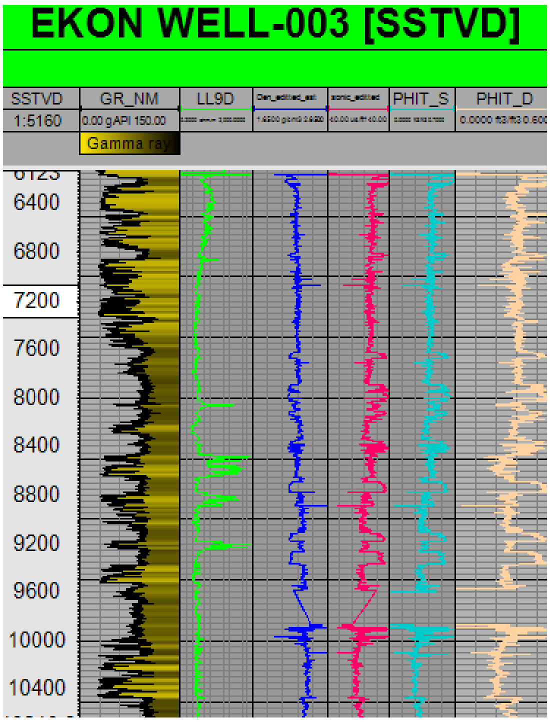


Figure 15: Overpressure prediction in EKON-002(Seismic Methods)



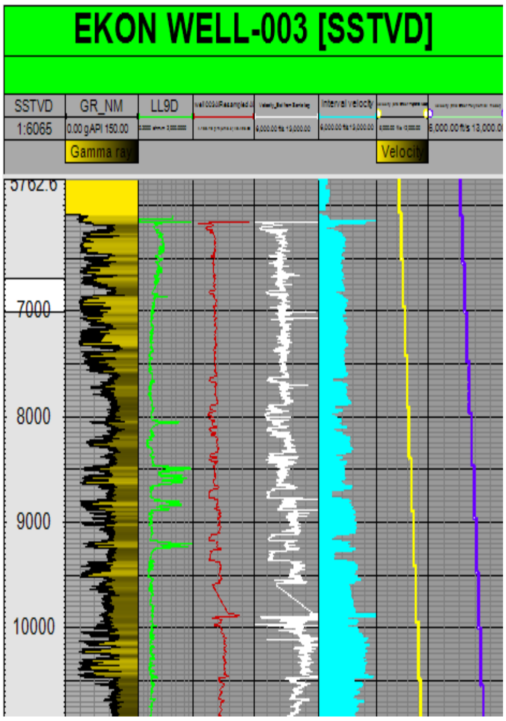
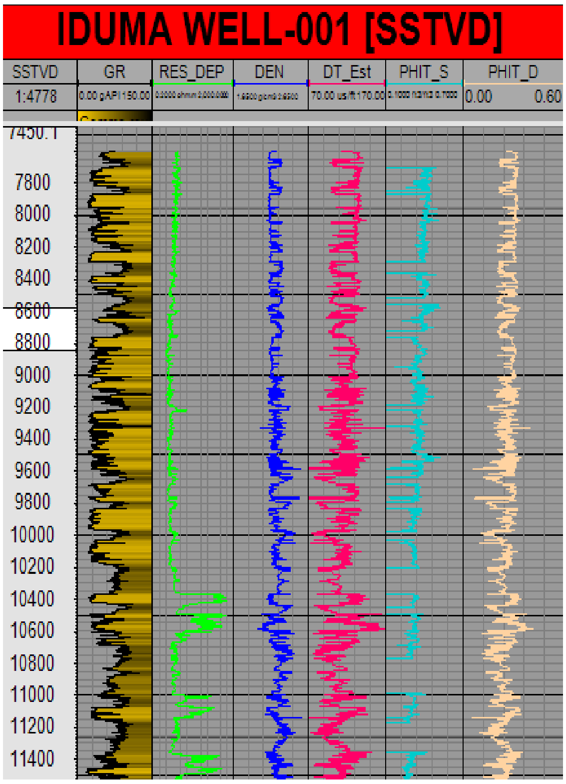


Figure 16: Overpressure prediction in EKON-003 (Well log Method)

Figure 17: Overpressure prediction in EKON-003(Seismic Methods)



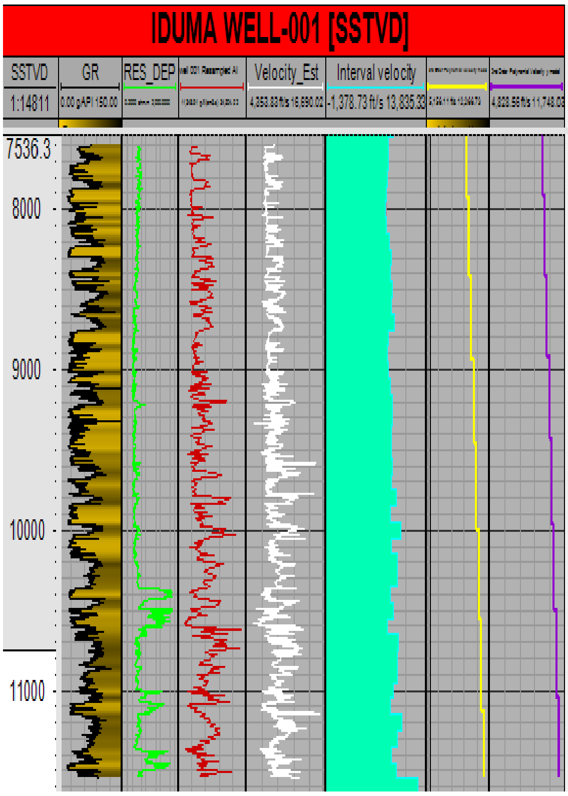
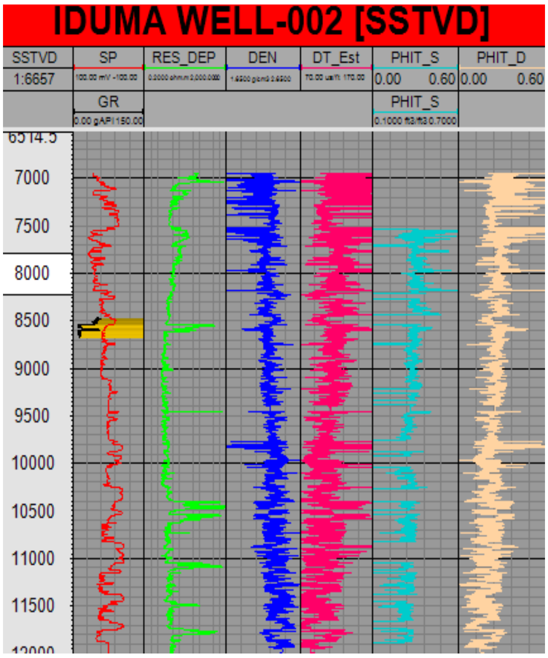


Figure 18: Overpressure prediction in IDUMA -001 (Well log Method)

Figure 19: Overpressure prediction in IDUMA-001(Seismic Methods)



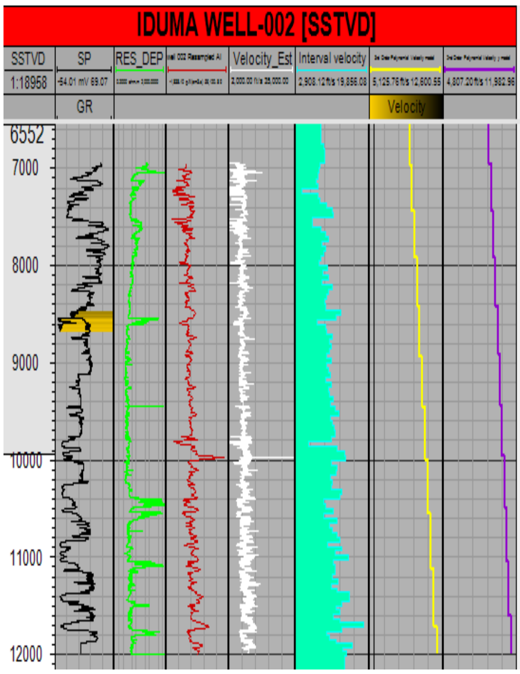


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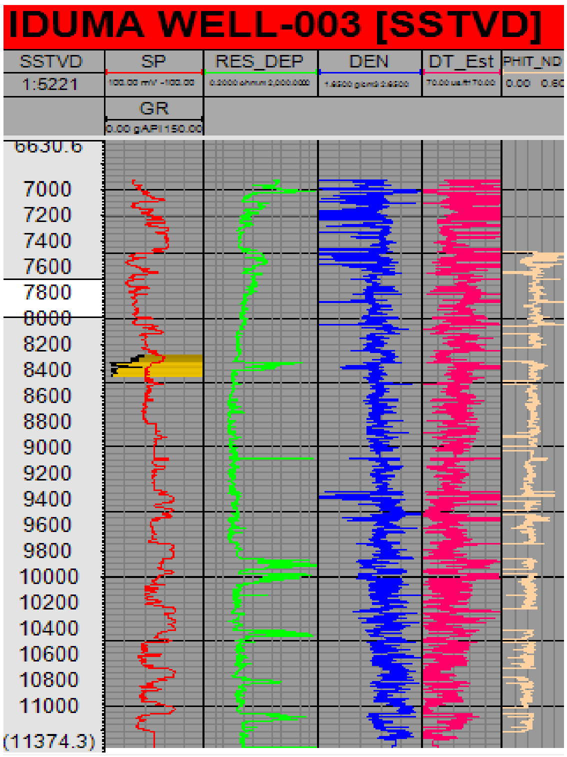
Figure 20: Overpressure prediction in EKON-001 (Well log Method)

Figure 21: Overpressure prediction in EKON-001(Seismic Methods)



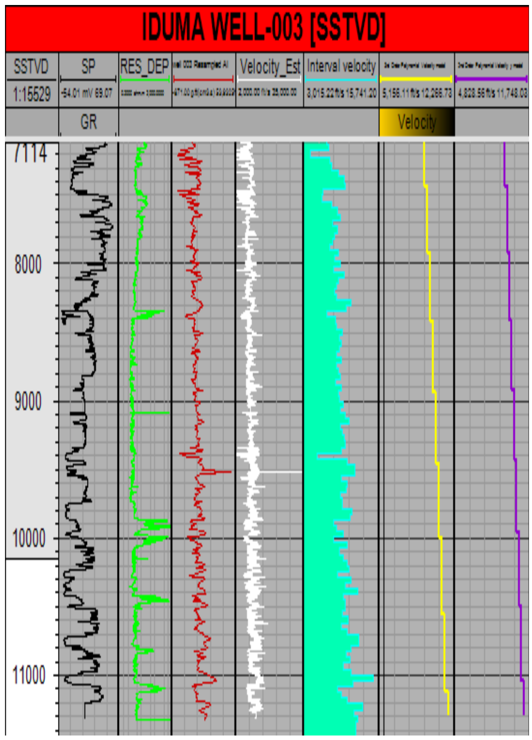
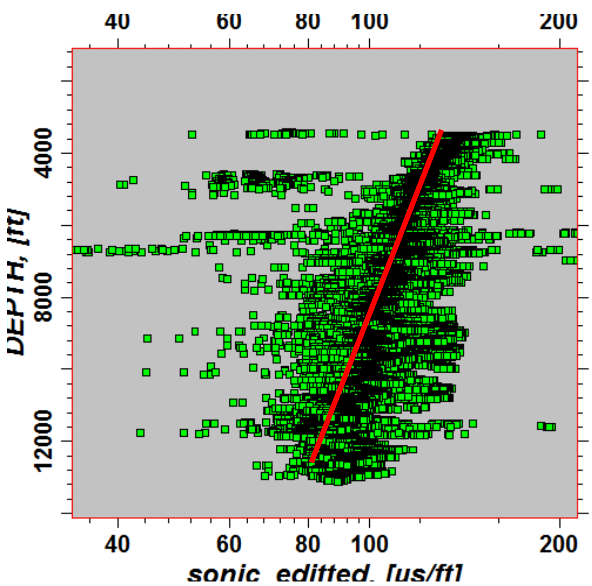


Figure 22: Overpressure prediction in EKON-001 (Well log Method)

Figure 23: Overpressure prediction in EKON-001(Seismic Methods)



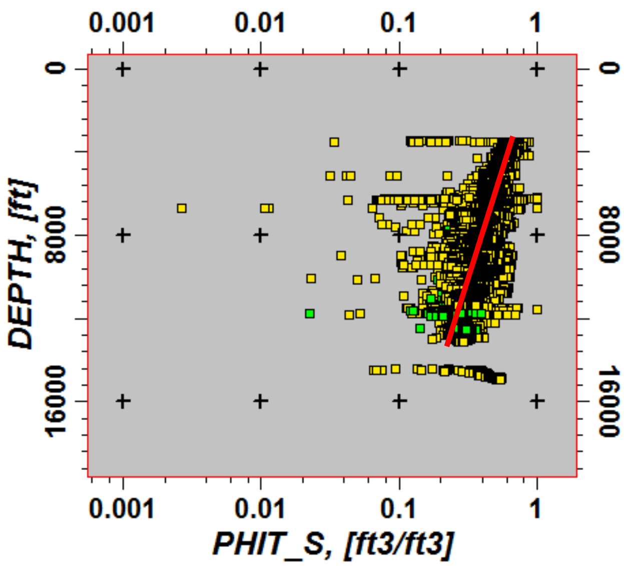


Figure 24: EKON sonic transit time vs. Depth plot

Figure 25: EKON sonic porosity vs.

Depth plot

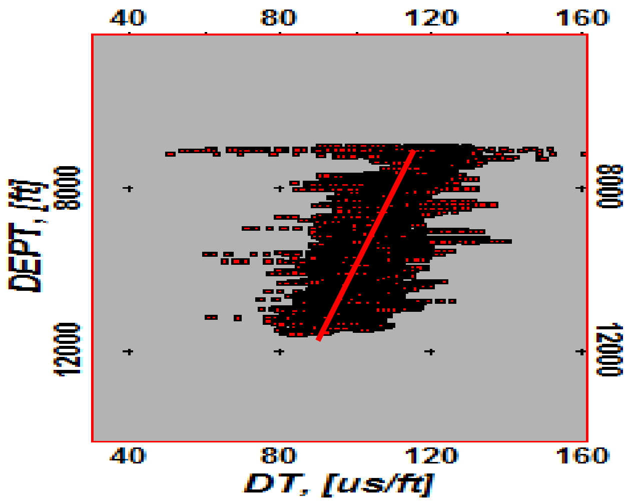


Figure 26: IDUMA sonic transit time vs. Depth plot

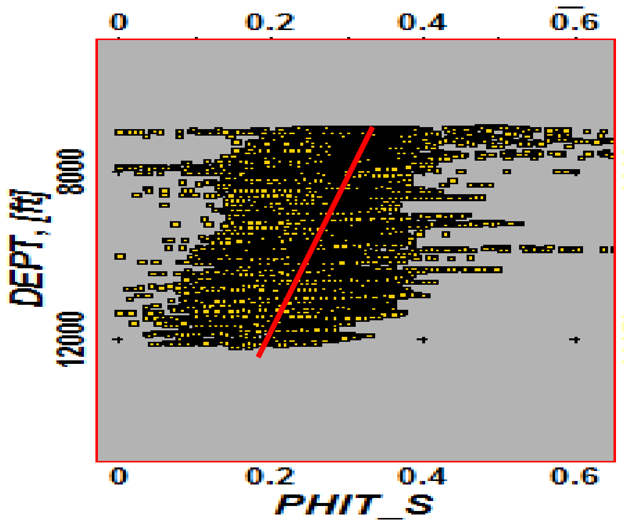


Figure 27: IDUMA sonic porosity vs. Depth plot

CONCLUSION

The following conclusions were drawn from this study:

The increased bulk density observed from thinning of the sand sequences at greater depths indicated compaction.

- The trapping mechanisms and structural style observed in EKON and IDUMA fields established pressure compartment; a prerequisite to overpressure.
- The quality and rating of the petrophysical properties delineated within the reservoir sand units of the EKON and IDUMA fields were pointer to over-pressured zones
- Overpressure zones predicted from well log data conformed to the results of the seismic methods.
- The correlated reservoir zones correspond to overpressure zones. thus, the tops of the delineated reservoir units conformed to the upper limits of the overpressure zones while the bases corresponded to the lower limits of the overpressure zones
- The primary mechanism of overpressure in the EKON and IDUMA fields as observed from the Eaton sonic transit time model and correlation was thought to be Compaction disequilibrum; while results from seismic interpretation revealed tectonism and hydrocarbon gradient as additional mechanisms of overpressure

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