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PORE PRESSURE PREDICTION USING WELL LOGS- A CASE STUDY OF A FIELD IN THE ONSHORE CENTRAL NIGER DELTA, NIGERIA

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ABSTRACT

Well overpressure remains the major cause of blow-outs and oil spills in well/reservoir production.. In this study, we predicted the in-situ pressure of the shale formations using well logs. One well obtained from a field (Field XXX) in the onshore central Niger Delta were analyzed to determine if there is a deviation in the normal compaction behaviour of the shales in this field since mechanical compaction disequilibrium is the major cause of geopressuring in shales. To accomplish this, we investigated the compaction behavior of shales using well data. Three composite parameters- sonic transit time/velocity, resistivity, and porosity- were used. For selected intervals, these composite parameters were each plotted against depth to show how each parameter behaves should the shales compact normally or otherwise. From the results obtained, a similar scenario prevailed in the compaction trend plots of the composite parameters with depth. Overpressure was found to occur in Interval A Section A of the Well (depth range 3691.07m – 3703.54m) and normal pressure in Interval B Section A (depth range 3731.54m – 3873.69m). Interval A Section Aa (depth range 4299.06m - 4328.32m) and Interval B Section Aa (depth range 4337.16m - 4354.07m) revealed the presence of overpressure. At such depths, the sonic transit time/velocity, resistivity and porosity deviated either to the left (lower values) or to the right (higher values) from the normal compaction trend. These are consistent results since geopressure occurs in zones where normal compaction of shales is mechanically disrupted.

Key Words: Pore Pressure, Geopressure, Compaction, Velocity.

INTRODUCTION

Well overpressure has been recognized as the major cause of oil spills in well/ reservoir production. Pre-drill warning and identification of zones or sections of overpressure/normal pressure in subsurface formations thus becomes imperative in order to mitigate production risks and hazards. Though pre-drill prediction of pore pressure (that is, warning prior to drilling) using surface seismic data, should of necessity, precede other forms of pressure prediction in reservoirs, identification of overpressured zones using well logs/measurements serves not only as a check but is also required for any conventional well design. Analyses and discussions in the literature have harped on the use of well data for in-situ prediction of pore pressure (Mukerji et al, 2002; Ruth et al., 2004; Ekpa, 2008,). The fundamental approach in the use of such data involves analysis of the compaction behaviour for shales, although analysis in Vp/Vs, σ (poison's ratio), Zp/Zs crossplot domains etc can also serve as a powerful diagnostic tool (Domenico, 1984; Dutta et al., 2002; Omudu and Ebeniro, 2005; Hoversten et al., 2006).

Compaction analysis using well logs entails plots of sonic time/Vp against depth, porosity against depth, density against depth and resistivity against depth which show how these rock parameters behave in undercompacted or normally compacted shales. Such plots have shown that geopressured zones in subsurface formations can be clearly delineated (Eaton 1975; Dutta and Ray, 1996; Dutta, 2002; Mukerji et al, 2002; Ruth et al., 2004; Ekpa, 2008). This yields a trendline that reveals the compaction behaviour of the shale lithology. In the high temperature and pressure clastic environment of the Niger Delta (especially in the deep water) where mechanical compaction disequilibrium is the natural cause of geopressuring, the trendline resulting from the plots of Vp against depth, porosity against depth, density against depth and resisitivity against depth, show a velocity, porosity, density and resistivity reversal at the point of deviation of the trendline, indicating the occurrence of geopressure or low effective stress in the undercompacted shale (Dominico, 1984; Kan and Swan, 2001; Mukerji, et al., 2002; Ekpa, 2008). Pore pressure (the pressure of pore fluid) usually exceeds hydrostatic pressure (pressure of a column of water) in the zone of low effective stress or geopressure in a well. Hence, the construction of the compaction trend model from well logs helps to detect the zone where pore pressure exceeds or is equal to the hydrostatic pressure, indicating overpressure or normal pressure. Overpressure occurs more in the deeper horizons (3500m - 4500m) in a well than in the shallower sections although geopressure and normal pressure can also be detected in the shallower sections especially in the frontier areas of the Niger Delta (Ekpa, 2008).

Discussions in the literature have highlighted various methods of pore pressure prediction.

Eaton (1975) had developed a model for pore pressure prediction. The model showed that the pressure conditions of reservoirs can be clearly revealed if adequate velocity information is available. If the velocity data are available, the pore pressure can be quantified using Eaton model or a velocity to effective stress rock transform model can be used to convert the velocity to pore pressure (Dutta, 2002).

Kan and Swan (2001) showed examples of pressure gradient caused by a lithology change, sealing faults and fluid migration flows. They analysed some well logs to determine lithology. Shale compaction trend was used to predict the variation with depth, Z, of the interval transit time of compressional sonic waves through the shale. From sonic logs, the geopressured zone was evident by the increase in the logged mud density correlated with the departure of the sonic transit time from the linear compaction trend extrapolated downward from the hydrostatic zone.

Sayers et al (2001) reported that though the use of seismic velocity for pore pressure prediction is well known, the interval velocities need to be derived using a method capable of giving a spatial resolution

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sufficient for well design. Normal moveout velocities average the velocities over the seismic aperture though they may not be suitable for pore pressure prediction in the presence of significant lateral variations of velocity. Reflection tomography gives improved spatial resolution of the seismic velocity field and this allows for a more reliable pre-drill pore pressure.

Mukerji et al. (2002) observed that well logs obtained after drilling are the most extensively used and reliable means to construct a compaction trend model and other rock models to delineate overpressure. They showed that overpressure zones in wells exhibit several of the following properties when compared to a normally pressured section at the same depth: higher porosities, lower bulk densities, lower effective stress, high temperature, lower interval velocities and higher Poisson's ratio. Their work also revealed that unconsolidated sediments are particularly susceptible to overpressures, and that Poisson's ratio or Vp/Vs ratio (obtained from shear wave information) can help to reduce ambiguities in seismic prediction of overpressure or normal pressure. The Poisson's ratio can be used to improve the reliability of traditional methods where only the compressional wave velocity and density or porosity are used.

Ebrom et al. (2004) reported that the understanding of effective stress in mudrock shale is not nearly as advanced as the understanding of effective stress in sandstone. Their method of pore pressure prediction relied on velocity prediction in mudstones and shales which comprise 70% of siliciclastic sediments. The use of effective stress should be recognized though it is an approximation to the actual physics. They recommended that more studies should be funded to quantify p-wave and s-wave velocity effective stress in mudrock, shale and silty sand. The use of s-wave velocity as an additional pressure prediction tool should be considered.

Ekpa (2008) worked on geopressure prediction in the Niger Delta by analysing well logs. She plotted several rock properties against depth and superimposing the hydrostatic pressure line on the plots, she found that geopressure occurs in the shales of the Niger Delta due to mechanical compaction disequilibrium resulting from low effective stress. Her results were consistent with the results of the previous work of Mukerji et al.,(2002) on in-situ prediction of pore pressure and showed that velocity, porosity, and density reversals occur in the geopressured zones.

Because the shale formations in the Niger Delta are prone to mechanical compaction disequilibrium leading to overpressure in the reservoirs, in this research we intend to use logs to analyse the compaction behaviour of the shales to enable us predict the pore pressure conditions of the well under investigation.

Geology of Field XXX

The well data used for this study were obtained from a field (Field XXX) located in the coastal swamp of the onshore central Niger Delta. The coastal swamp actually lies south of the Central Niger Delta and is bounded by the East and West Niger Delta. The field is structurally characterized by anticlinal features and faults, and produces oil and gas in a predominantly detaic sequence consisting of alternating sand and shale layers. The hydrocarbon resources are trapped in faults of complex geometries.

Stratigraphically, the upper sections of the field consist mainly of sand layers while the deeper horizons comprise a sequence of alternating sand and shale formations.

It has been found from literature that velocity, V_P/ V_s ratio, Poisson's ratio, resistivity, porosity and density can be utilized in well log techniques to unravel zones of geopressure and/or normal pressure through the section of a well (Kan and Swan, 2001; Dutta et al., 2002; Mukerji et al., 2002; Ekpa, 2008).

A rock is said to be overpressured when its pore pressure is significantly greater than hydrostatic pressure. Normal pressure implies that the pore pressure is equal to the hydrostatic pressure. Pore pressure is the in-situ pressure of the fluids in the pore and is also known as formation pressure. Hydrostatic pressure gives the pressure due to a column of water. The point at which pore pressure exceeds hydrostatic pressure of the fluid in the pore space is known as top of overpressure. Lithostatic or confining pressure is the pressure exerted due to the weight of sediment including the pore fluid. This is also known as overburden stress or pressure. The difference between the overburden pressure and pore pressure is called differential pressure or effective stress. Mathematically, Terzaghi (1943) states that

$$\sigma = s - p \quad (1)$$

where σ is the effective stress or differential pressure, s is the overburden pressure and p is the pore fluid pressure. It is σ that controls the compaction process in sedimentary rocks. Any condition at depth that causes a reduction in σ will also reduce the compaction rate and result in geopressure. It has been found that the major cause of overpressure in the Niger Delta is mechanical compaction disequilibrium, which usually results in low effective stress, low velocity, high Vp/Vs ratio or Poisson's ratio and high porosity.

METHODOLOGY

Compaction Plots Analysis

This involves plotting different parameters against depth for selected shale intervals to help in detecting the point of deviation of a parameter from the hydrostatic trend. It is known that mechanical undercompaction in shales is responsible for geopressuring in the Niger Delta. Hence, if compaction plots are analysed, a rock property will be found to deviate from the normal or hydrostatic trendline in the zone of overpressure. The point of deviation of the rock property from the normal compaction trend is known as the top of overpressure (Kan and Swan, 2001; Dutta, et al, 2002, Ruth et al., 2004). Goepressure occurs mainly in thick undercompacted shales at the deeper horizons but may also be observed in shallow sections of wells (Ekpa, 2008). The rock properties of interest in the compaction trend plots to detect geopressure or normal pressure include velocity, resistivity, density and porosity. Our interest is to determine how each parameter behaves during normal or abnormal compaction of shale. Thus, our plots can help to clearly reveal the absence or presence of geopressure in a well. Overpressured formations exhibit several of the following properties when compared with a normally pressured section at the same depth: lower interval velocities, high porosities, lower bulk densities, lower effective stress, higher temperature and higher Poission's ratio (Mukerji, et al.,

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2002; Ruth et al., 2004; Presgraf, 2007)

RESULTS

Data Presentation

Composite well logs in digital format obtained from a field (Field XXX) in the onshore Niger Delta are presented and analyzed on a crossplot plane. One well, designated Section A and Section Aa is provided. Section Aa represents the deeper sections of the Well.

Section A contains a suite of composite logs in the digital form namely the Gamma Ray (GR) log, porosity log, resistivity log and sonic transit time log, the logging resolution being in the order of 0.025m. Section A has a depth range of 2390m to 3990m. However, the composite logs are incomplete over this depth range.

Section Aa, with a depth range between 3990m and 4398m, contains the GR log, resistivity log, porosity log and bulk density log. The logging resolution is in the order of 0.152m. The sonic log (sonic transit time) is completely absent for all depths in this section. We have thus used the Wiley Average time equation to model this log because of its critical importance in the pore pressure prediction analysis. The density log is incomplete in Section A and Section Aa and therefore has not been used in this analysis. Field XXX is a known field containing hydrocarbon reservoirs, overpressured and normally pressured shales.

Lithological Classification

The lithologies observed in the entire depths of investigation (2390m to 3990m for Section A, and 3990m to 4398m for Section Aa) include the sand and shale sequences and were determined from the interpretations of the GR log (Fig.1(a and b)).

Table 1: The Lithologies for Entire Depths of Investigation in Sections A and Aa.

Section	Depth Range (m)	Lithologies
Section A	2390 – 3990	Sand / shale sequence
Section Aa	3900 – 4398	Sand / shale sequence

Table 2: Working Intervals And Associated Lithologies.

Section	Working Interval	Depth (m)	Associated Lithology
A(Shales)	A	3691.07 – 3703.54	Shale
	B	3731.54 – 3873.69	Shale
Aa(Shales)	A	4299.06 - 4328.32	Shale
	B	4337.16 - 4354.07	Shale

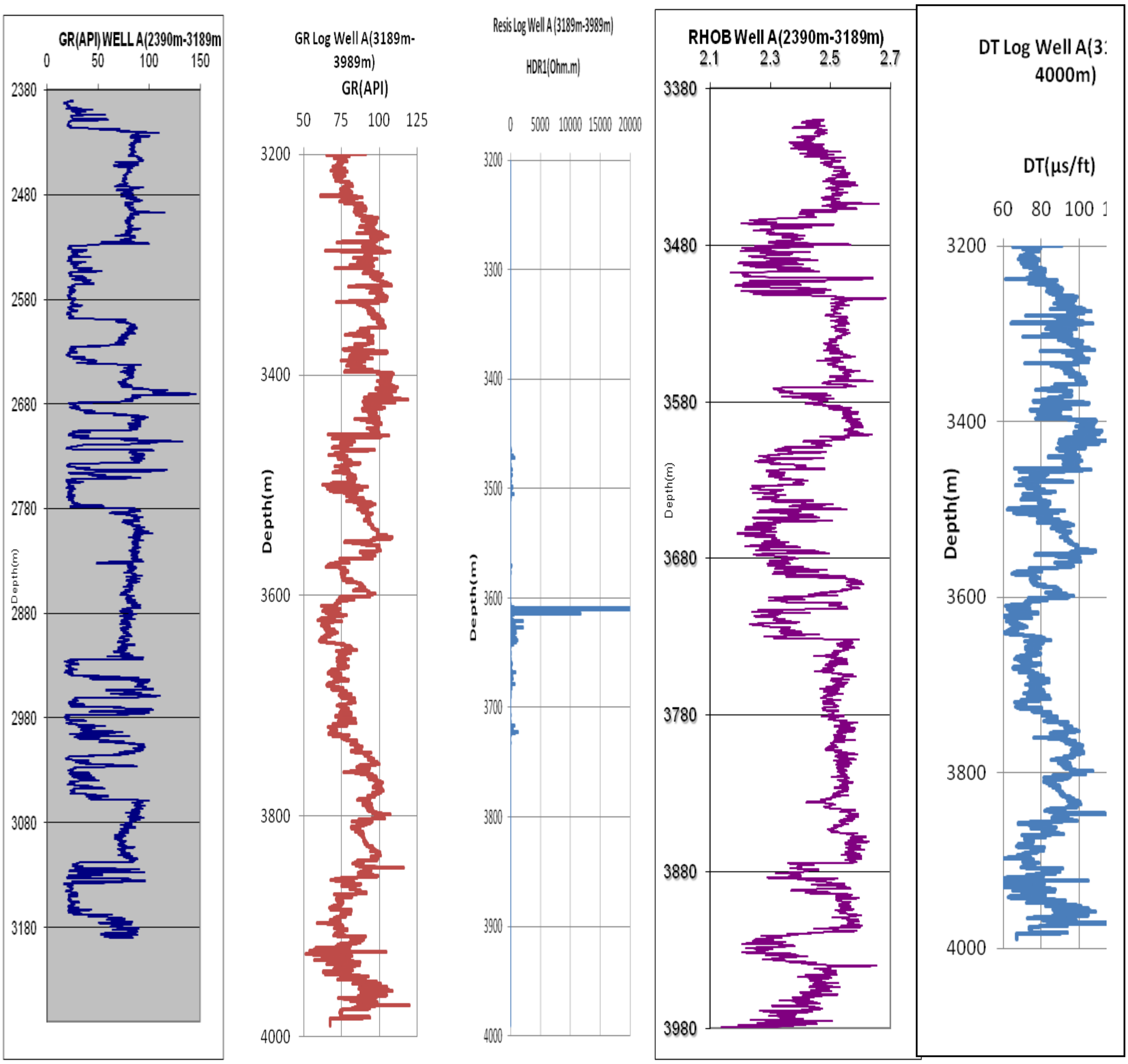

Fig.1(a): **The Logs For Section A of the Well. The GR log was used for lithology Interpretation**

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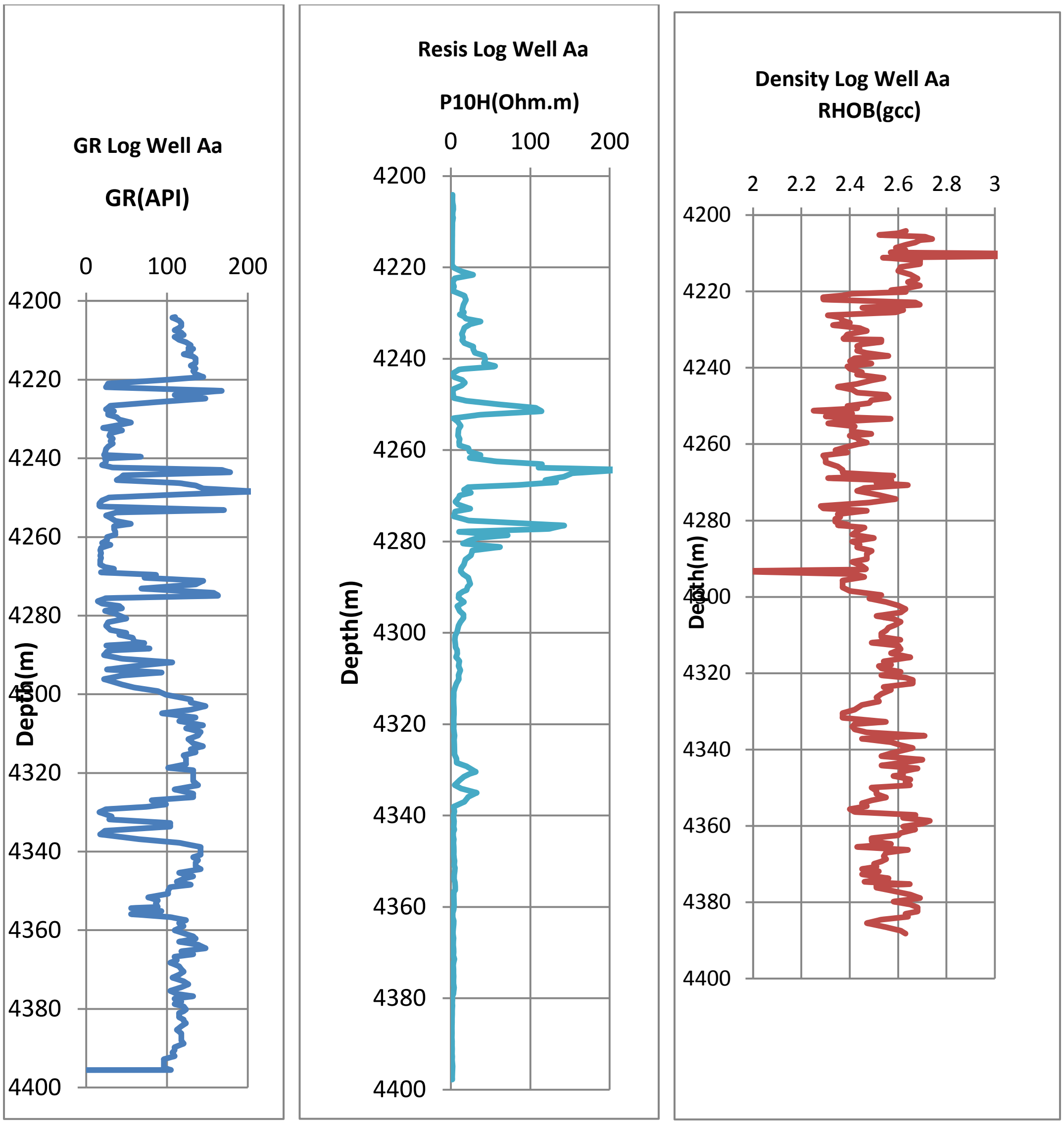

Fig.1(b): The logs for Section Aa of the well (Sonic data absent in these depths) .

Sonic Transit Time (DT) Versus Depth in Section A

Sonic transit time versus depth plot shows transit time decreasing with depth for a normally pressured zone. In the overpressured zones, DT invariably increases (meaning low velocity zone). As shown in the figures (Fig.2 (a and b)), the encircled points are the center of attention. The depth point where the sudden change or deviation begins is known as the top of the overpressure. Working Interval A shows a deviation in DT from depth 3692.92m (top of overpressure) to 3697.82m, indicating that interval A is an overpressured shale (Fig.2a). Working Interval B shows normal pressure as there is no deviation in DT from the normal compaction trend (Fig. 2b).

Resistivity Versus Depth in Section A

Resistivity values are plotted against depth for working Intervals A and B. The points of deviation from the normal trend are delineated with ovals. In Interval A, resistivity begins to decrease from the normal trend from the depth 3692.59m to 3697.47m showing overpressure in this interval (Fig.3a). In working Interval B, there is no remarkable deviation in resistivity from the normal compaction trend; hence this zone has normal pressure (Fig.3b). The results of sonic time plots with depth in Intervals A and B, are thus found to correlate well with those of resistivity plots with depth in the same intervals.

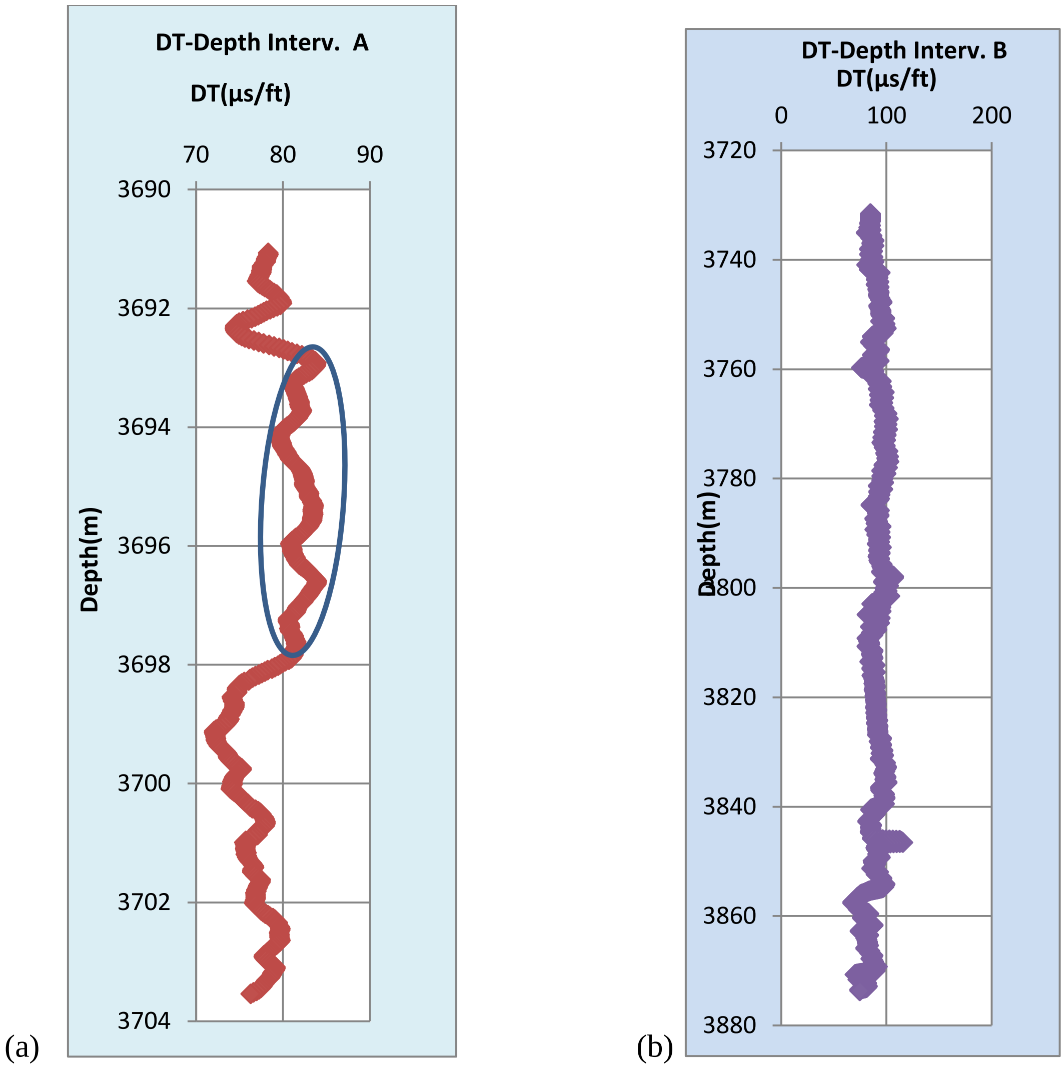

Fig.2 (a and b): The sonic time versus depth plots for Intervals A and B of Section A, indicating overpressure in Interval A (Oval). Normal pressure is observed in Interval B.

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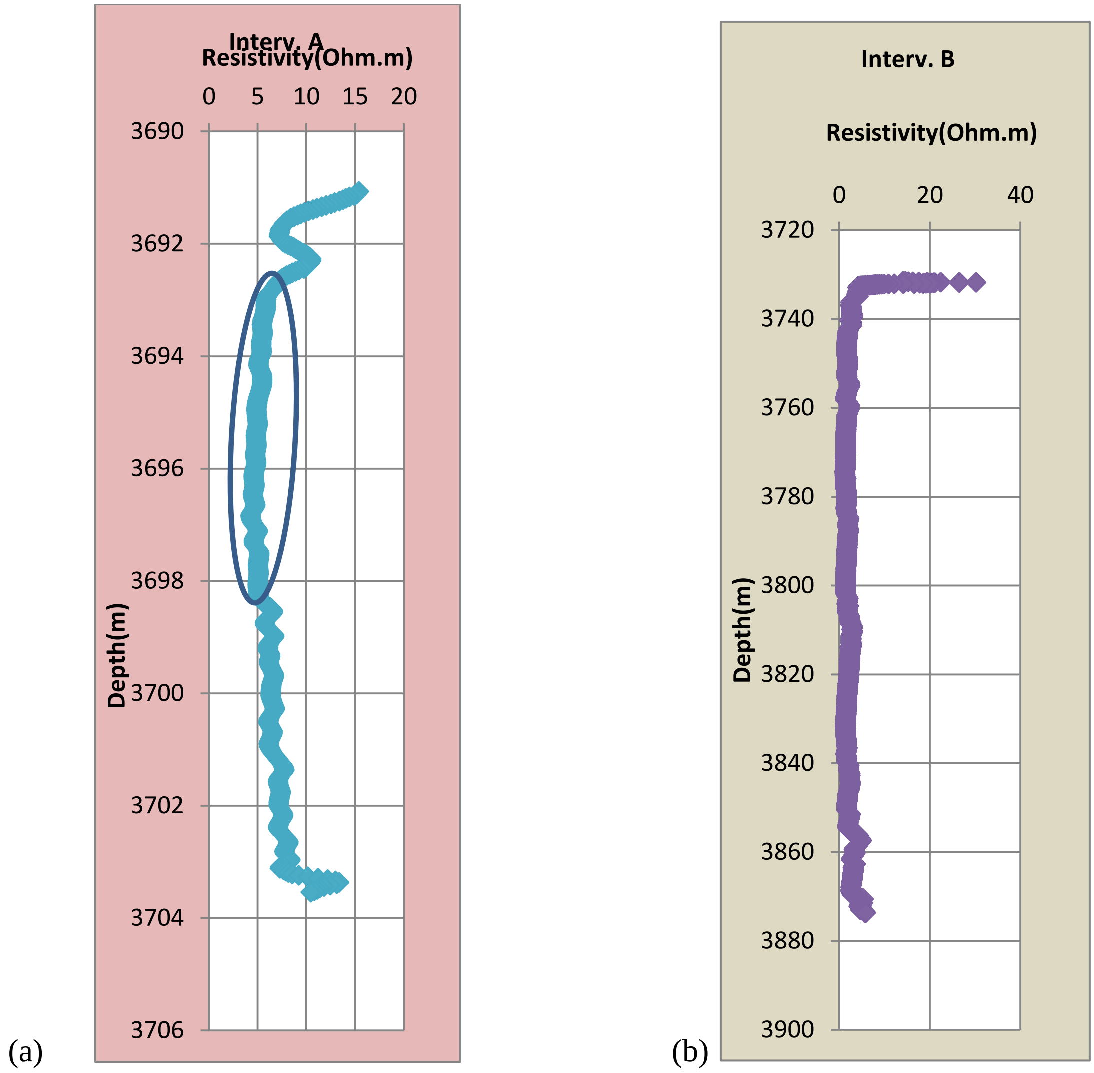


Fig.3 (a and b): The resistivity versus depth plots for Intervals A and B, indicating overpressure in Interval A (Oval). Normal pressure is observed in Interval B.

Porosity Versus Depth Plot in Section A Intervals

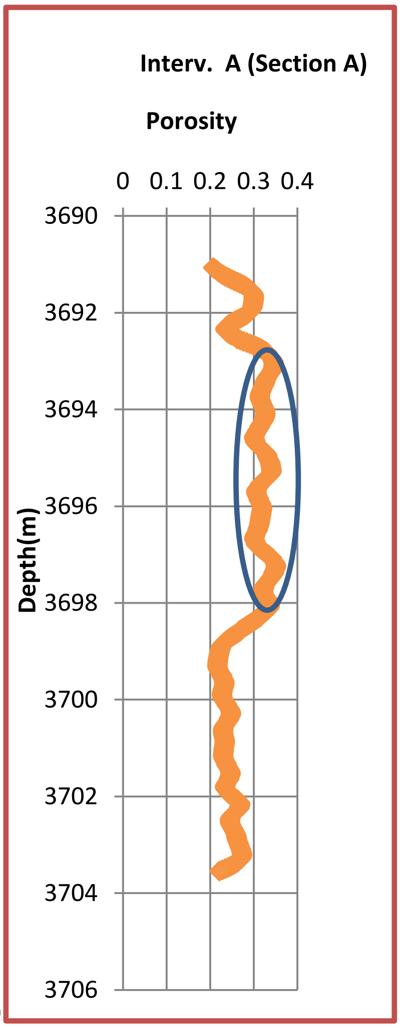
Working Interval A shows porosity increase (or deviation) from the depth 3692.67m (top of overpressure) to 3697.07m indicating overpressure in this zone, a result consistent with the DT – depth and resistivity – depth plots (Fig. 4a). Working Interval B shows no remarkable deviation in the porosity – depth plot and therefore clearly indicates a normally pressured shale interval (Fig. 4b). The density plot with depth is unavailable due to absence of data at that depth interval, but the general scenario observed in the composite plots with the sonic, resistivity and porosity data clearly shows that our results are consistent and any conclusion drawn from them is less likely to be misleading.

Sonic Transit Time (DT) Versus Depth Plot in Section Aa

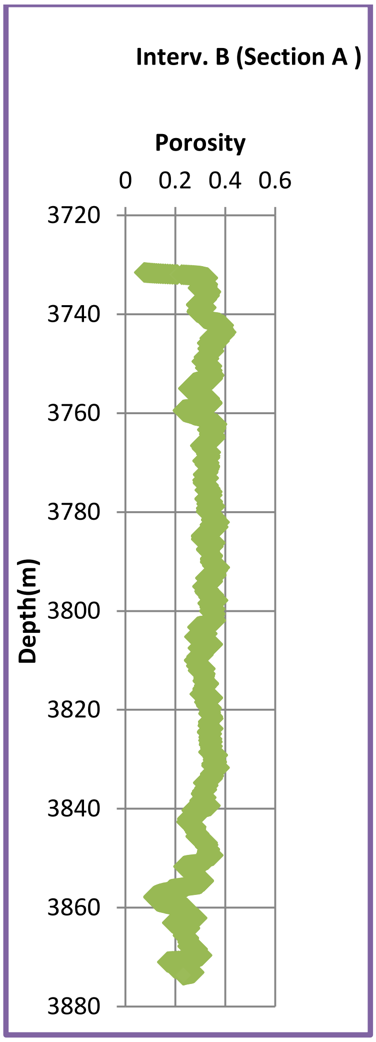
Two working intervals (A and B) have been selected for Section Aa for the DT versus depth plots (compaction trend plot). In Interval A, DT does not show a remarkable increase from the depth 4311.55m (top of overpressure) to 4323.44m, and hence does not, as expected, indicate a characteristic low velocity and overpressure in this zone (Fig.5a).This is probably due to inconsistency of sonic log data in this zone. In Interval B, DT-depth plot shows remarkable increase in sonic time (deviation from the compaction trend) from the depth 4338.68m (top of overpressure) to 4344.93m, showing a characteristic low velocity and overpressure in this zone (Fig.5b).

Resistivity-Depth Plot in Section Aa

The resistivity depth plot for Interval A shows a deviation (decrease in resistivity) from the depth 4311.55m (top of overpressure) to 4323.44m indicating mechanical compaction disequilibrium and overpressure in this zone (Fig.6a). Working Interval B shows a deviation from the normal compaction trend from the depth 4338.22m to 4345.84m, indicating low resistivity and overpressure in this shale zone (Fig. 6b).



(a)



(b)

Fig. 4 (a, b): The porosity versus depth plots in Section A showing overpressure in Interval A (Oval) and normal pressure in Interval B.

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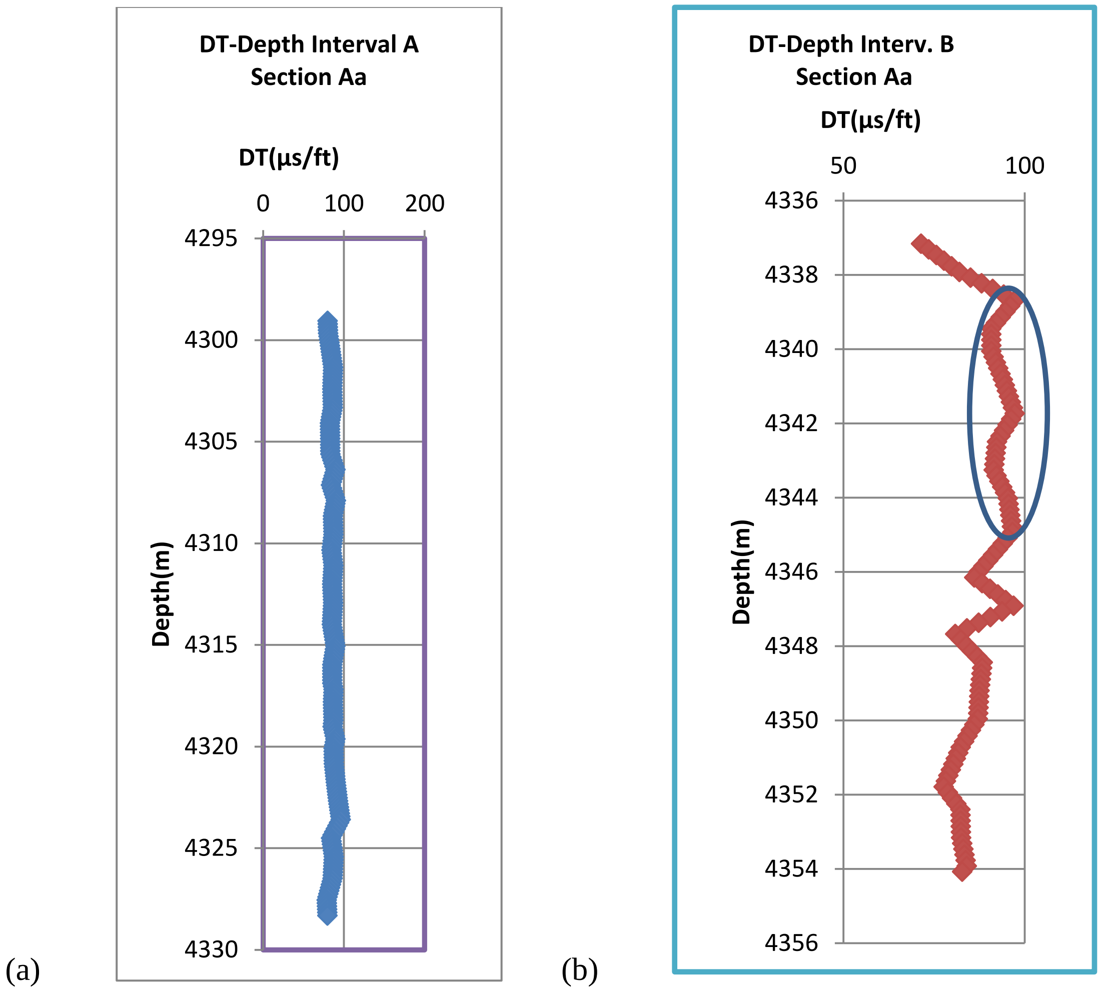
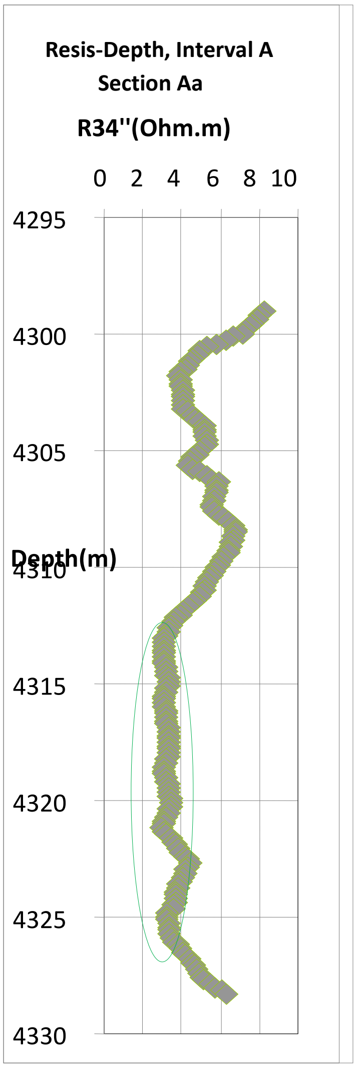
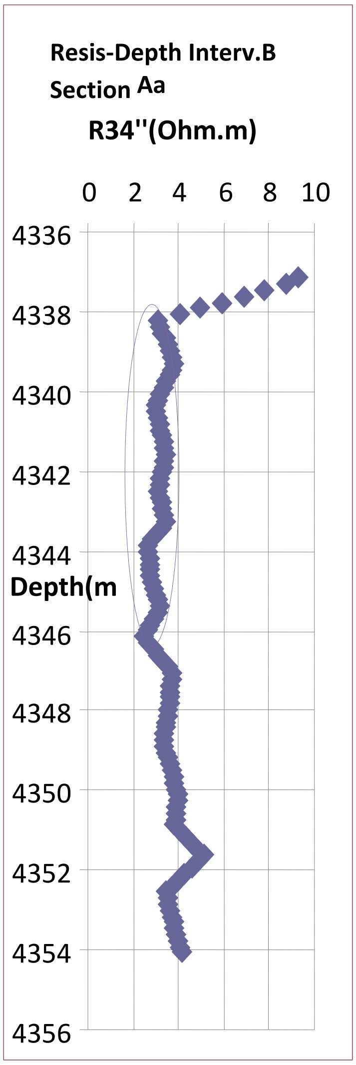


Fig. 5(a and b): The DT (sonic transit time) versus depth plots for Intervals A and B in Section Aa, indicating overpressure in Interval B (oval).



(a)



(b)

Fig. 6(a and b): The resistivity versus depth plots for Intervals A and B in Section Aa, showing overpressures in the depth intervals (Ovals).

Porosity – Depth Plots in Section Aa

Working Interval A shows a deviation from the trend from the depth 4305.91m (top of overpressure) to 4321.76m, indicating high porosity zone (anomaly) and occurrence of overpressure in this under-compacted shale zone (Fig. 7a). Interval B shows an anomalous increase in porosity from the depth 4338.68m to 4344.94m, also indicating overpressure in this zone (Fig. 7b).

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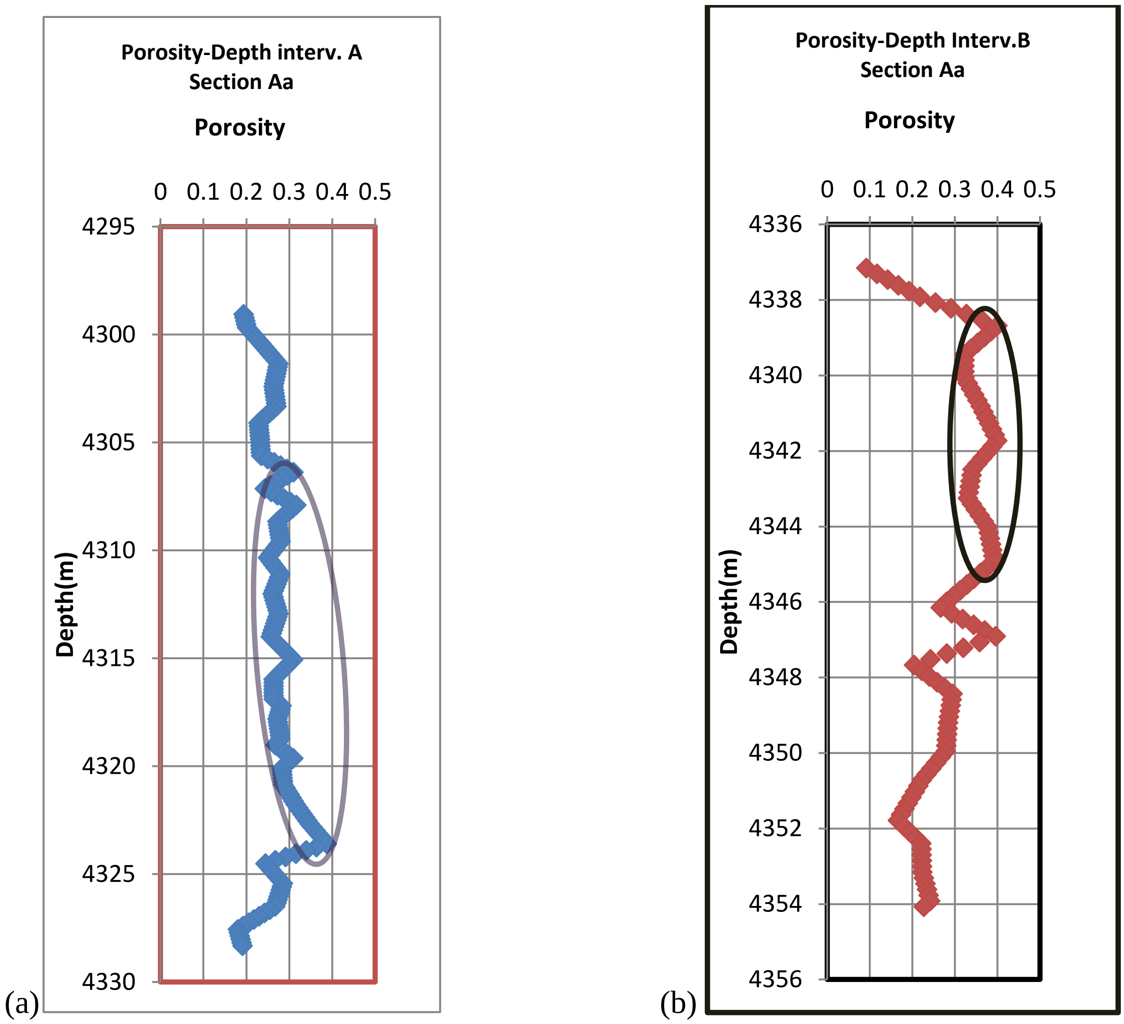

Fig. 7 (a and b): The porosity – depth plot revealing overpressure in Intervals A and B in Section Aa (ovals).

DISCUSSION

We have carried out the compaction trend plots of three composite rock parameters with depth to show how each parameter behaves when shales are compacted normally or under-compacted. Normal pressure prevails at the depth/zone of normal compaction and overpressure at the depth/zone of mechanical under-compaction. Our results clearly show that overpressured shales generally exhibit the following properties: increased sonic transit time (lower velocity) lower resistivity, and higher porosity as observed from their deviations from the normal compaction trend at the depths of observed geopressure. More interestingly, the different rock parameters in the plot domain gave precisely the same results at those depths/zones where overpressure prevails except the sonic transit time (DT)-depth plot in Section Aa, probably due to inconsistency of sonic time log data at that zone. Interval A of Section A (depth range 3691.07m – 3703.54m) suffers from overpressure because the composite rock parameters plotted against depth deviated from the normal compaction trend at that zone. Interval B of Section A (depth range 3731.54m – 3873.69m), however, shows normal pressure or absence of geopressure as the plots of the composite parameters with depth revealed normal compaction of the shale throughout the depths of the interval. The same scenario was observed in the compaction plots for Interval A (depth range 4299.06m - 4328.32m) and Interval B (depth range 4337.16m - 4354.07m) of Section Aa. Overpressure was observed in this section at the selected intervals due to the deviation of sonic time, resistivity and porosity from the normal compaction behaviour. These results are indeed consistent with the research observations of Dutta, et al. (2002); Ruth et al. (2004); Presgraf (2007); and Ekpa (2008). Overpressured shales are low velocity formations that exhibit washouts, kicks, borehole instability and, in the extreme case, blowouts.

(i) More wells are needed to determine if the observed trend in the compaction plots of the composite parameters with depth shows prevail with regard to the field under study.

(ii) The hydrostatic pressure profile of the well was unavailable. Superimposing the hydrostatic pressure profile on the compaction plots is required to add more information on the true state of the formation pressure of the well.

(iii) Further investigation of the pressure condition of wells/formations could rely on Vp/Vs, poison ratio, and Zp/Zs cross-plots. These rock attributes can serve as a powerful diagnostic tool in pore pressure prediction.

This study has shown that the in-situ pressure of wells can be determined if the rock properties-sonic time/velocity, resistivity and porosity- are plotted against depths. These plots, known as compaction trend plots, are thus helpful when there is need to predict pore pressure prior to any conventional well design and drilling in order to mitigate production risks and hazards.

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REFERENCES

Aki, K., and Richards, P.G. (1980) Quantitative Seismology: W.H Freeman and Co.

Buland, A., and Omre, H. (2003b) Bayesian Wavelet Estimation from Seismic and Well Data: Geophysics, 68, 2000 – 2009.

Domenico, S.N. (1984) Rock Lithology and Porosity Determination from Shear and Compressional Wave Velocity: Geophysics, 49, 1188 – 1195.

Dutta, N., Mukerji, T., Prasad M., and Dvorkin, J. (2002) Seismic Detection and Estimation of Overpressure: WesternGeco, Houston, Texas USA Standford Rock Physics Laboratory, Standford, Californ USA, CSEG Recorder.

Dutta, N.C., and Ray, A. (1996) Subsurface Image of Geopressured Rocks using Seismic Velocity and Acoustic Impedance Inversion: 58th Annual

Scientia Africana, Vol. 16 (No. 1), June 2017. Pp 161-175
© Faculty of Science, University of Port Harcourt, Printed in Nigeria *ISSN 1118 – 1931*

meeting Euro. Assoc. Geosci. Eng., Amsterdam (Extended Abstract).

Dutta, N.C. (2002) Geopressure Prediction Using Seismic Data: Current Status and the Road Ahead: Geophysics, Vol 67, No 6, P2012 – 2041.

Ebrom, D., Heppard, P., Thomson, L., Muller, M., Harrold, T., Phillip, L., and Watson, P., (2004) Effective Stress and Minimum Velocity Trends: SEG Int'l Exposition and 74th Annual Meeting, Denver, Colorado 1015, BP, Exploration and Production Technology Group, Houston, Texas and BP Trinidad.

Ekpa, N. U. (2008) Detection and Estimation of Overpressure Using Well Logs from Oil Fields in the Niger Delta: M.Sc Thesis, Department of Physics/Applied Geophysics, University of Port Harcourt, Nigeria.

Hoversten, G.M., Cassassuce, F., Erika, G., Newman, G. A., Chen, J., Rubin, Y., Hou, Z., and Vasco, D. (2006) Direct Reservoir Parameter Estimation Using Joint Inversion of Marine Seismic AVA and Controlled – Source Electromagnetic (CSEM) Data: Geophysics, V11, No3, C1 – C13.

Kan, K.T., and Swan, H.W.,(2001) Geopressure Prediction from Automatically Derived Seismic Velocities: Geophysics, Vol 66, No 6.

Ma, X. (2002), Simultaneous Inversion of Prestack Seismic Data for Rock Properties Using Simulated Annealing: Geophysics, Vol 67, No 6, 1877 – 1885.

Mukerji, T., Dutta, N., Prasad, M., and Dvorkin, J. (2002) Seismic Detection and Estimation of Overpressure (The Rock Physics Basis): Stanford Rock Physics Laboratory, Stanford California USA and Western Geco, Houston Texas USA CSEG Recorder, p34 – 57.

Omudu, L. M., and Ebeniro, J. O. (2005) Crossplot of Rock Properties for Fluid Discrimination, Using Well Data in Offshore Niger Delta: Nigerian Journal of physics, Vol. 17, 16-20.

Omudu, L.M. (2007) Extraction of Rock Properties from Seismic Amplitude Data and Application to AVO Analysis in the Onshore Niger Delta: Ph.D Dissertation, Department of Physics/Applied Geophysics, University of Port Harcourt, Nigeria.

Ruth, **V.**, John, P., Hillis, R., and Tingate, P. (2004) The Origin of Overpressure in the Carnavon Basin Western Australia from Porosity Effective Stress Analysis.

Sayers, C. M., Woodward, M. J., and Bartman, R.C. (2001) Pre−drill Pore Pressure Prediction Using 4D Seismic Data: Schlumberger, Western Geco and Devon Energy, Houston, Texas, USA, The Leading Edge, p1056 – 1059.

Terzaghi, K. (1943) Theoretical Soil Mechanics: John Wiley and sons Inc.

Wang, J., Dopkin, D., and James, H (2004) Visualization for Pore Pressure Prediction: Eage, p1-6.

Yilimaz, O. (2000) Seismic Data Processing, Volumes 1 and 2, 2000, Society of Exploration Geophysicists, Tulsa, Oklahoma.