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Analysis of Hydrostatic Pressure Zones in Fabi Field, Onshore Niger Delta, Nigeria

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Abstract

The Analysis of hydrostatic pressure of Fabi Field onshore Niger delta was carried out to understand the subsurface depth pressure variations in the field. The well logs were analyzed to identify hydrostatic pressure zones through points of deviation from the compaction trends of the sediments and attribute crossplots while seismic inversion was carried out on the seismic data to obtain the lateral hydrostatic pressure variations in Fabi Field. The well logs exhibited normal compaction trends from depth level of 7200 ft to 8625 ft. At depth level of 8625 ft to 9000 ft, the velocity, density and resistivity logs deviated from the normal compaction trends. This point of deviations from the compaction trends of the sediments were identified as overpressure zones. Through crossplots of velocity and density logs, two overpressure generating mechanism of the Fabi Field such as under compaction and unloading were revealed. The under compaction was characterized by a linear drop in velocity and increase in density with depth while Unloading is characterized by abrupt decrease in velocity and at constant change in density. The results of acoustic impedance inversion revealed the lateral hydrostatic pressure variations of the Fabi Field. The onsets of over pressure zones are found around 1600 ms to about 1630 ms while very high overpressure gradients occur between 1950 ms to 2150 ms. These zones are characterized by very high acoustic impedance. The area extents of the positive anomalies (increase in acoustic impedance) are mostly consistent with the pressure while negative anomalies (low acoustic impedance) are interpreted as reservoir or sand zones.

Keywords: Well logs; Pressure zones; Acoustic impedance; Hydrostatic pressure; 3D Seismic; Wavelet analysis; Crossplots analysis

Introduction

In study of pore pressure, physical properties of subsurface formation with hydrostatic pressure are encountered worldwide during hydrocarbon exploration. Hydrostatic pressure as use here is simply the pore pressure at normal conditions. This occurs as a result of under-compaction due to rapid burial of the sediments. Rapid processes of deposition and sedimentation that builds up the basin have resulted into under-compaction at subsurface depths. If the loading process is rapid, fluid expulsion through compaction is seriously impeded, especially in fine-grained sediments with low permeability such as silts or clays. This confining layer that seal up the reservoir retard the escape of pore fluids at rates good enough to compensate for the rate of increase in vertical stress induced by the overlying beds and thus the pore fluid pressure begins to carry a large part of the load resulting to abnormal increase in pore fluid pressure. In many cases the shale pressure, and hence magnitude of overpressure, based on sedimentation rate is linked to the process of compaction disequilibrium although is empirical. This pressure tends to affect the seismic or sonic velocities where possible, thereby posing significant threats to drilling safety. The cost of mitigation is very high, to the tune of $1.08 billion per year world-wide. Dutta [1] discussed causes of overpressure and various ways to detect such a phenomenon. Boer et al. [2] presented a paper describing an approach used to estimate subsalt pore pressure in deep water Green Cayon area of Gulf of mexico. In their approach, they use a tomographyically derived 3D estimate of seismic velocity. The quality of seismic velocities allows an acurate velocity model of 3D salt distribution to be defined, the precise delineation which is essential for pore pressure prediction. Amonpantang [3] explained that methods for pore pressure estimation can give the approximate value of pore pressure but not the exact number. He reports that using well sonic data is the most suitable method for overpressure estimation. Real Formation Tester data is the measure of pore pressure that is used to compare with the predicted Pore pressure. Yu [4] reports that to meet today's challenge of high drilling cost and green environmental requirements and to obtain accurate and quantitative pore pressure information, pore pressure analysts are to know the abnormal pressure causes and building a good model. Solano et al. [5] reported that using the ratio between exponent and effective stress, pore pressure can be estimated more accurately than the standard exponent method for shaly formations. This approach is more objective for the definition of the normal compaction trend, because normal compaction trend is defined for the entire field rather than for individual wells. According to Standifird et al. [6], different measurements of the overpressure estimation which can be used to understand rock and fluid properties are based on three sources of data; Logging while drilling (LWD), wire line logging and seismic reflection surveys.

In this paper, we concentrate on the use of seismic and well log data in determination of overpressure zones. Seismic and well log data are very important in understanding of geopressured formation zones before and after drilling respectively. In prediction of abnormal pressure during drilling, the technique is based on mechanical drilling data (rock strength computed from rate of penetration (ROP), weight on bit (WOB) and torque). The rate of penetration is monitored to signal the penetration into overpressure zones, especially, if there is a transition zone. However, since is not easy to keep other drilling

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parameters constant, this method is not very reliable thus, is not considered in this research. In detection of abnormal pressure zones in Fabi Field, we construct rock model and predict overpressure by identifying the deviation points from their normal compaction trends of sediments from well logs and seismic inversion. Our objective is to identify hydrostatic pressure zones in the study area.

Location of the study area

The field name is Fabi. It is located some kilometres southwest of Port Harcourt province in Onshore Niger delta, Nigeria as shown in Figure 1. The area is situated on the continental margin of the Gulf of Guinea in West Africa at the south end of Nigeria. The Niger delta lies between Latitude 4° and 7° N and longitude 3° and 9° E bordering the Atlantic Ocean on the southern end of Nigeria. The northern boundary is the Benin flank and the North-eastern boundary is defined by cretaceous outcrop of Abakiliki High and southeastern end by Calabar flank. The province covers 300,000 Km and includes the geologic extent of the tertiary Niger delta (Akaka-Agbada) petroleum system [7-13].

Materials and Methods

Research data were provided by Shell Petroleum Development Corporation, Eastern division, Port-Harcourt in Rivers state, Nigeria. The data includes well logs and 3D seismic data, from Fabi Field, onshore Niger delta oil field.

The data were given with strict confidentiality for security reasons. The well logs were digitized in LAS format. Data interpretations and analysis were carried out using HRS program. Wire line log data comprise sonic log, density, resistivity log, caliper log, porosity log, and gamma ray log [14]. The inverse of the interval transit time of the sonic log were used to generate a compressional and shear wave velocity for each well. The well logs were marked with spurious events such as high frequency noise, and invasion problems. They were subjected to various corrections or editing so as to limit the possible interpretational error. The logs were despiked using media filtering, to ensure that they contain only appropriate range of values (Figure 2). The media filtering operation replaces the sample value at the centre of the operator. The longer the operator length, the smoother the log signatures. This process was largely experimental in order to isolate the best log operator length, we found that with an operator length 25, the logs were largely well smoothened. Figure 2 shows the difference between the non despiked well log using media filter and despiked well log respectively [15]. The data were subjected to wavelet analysis. Wavelet is defined by both amplitude and phase spectrum. We applied two wavelet extraction processes in the research. These include statistical and well log wavelet extraction. Statistical uses seismic traces alone to extract wavelet by Weiner- Levinson deconvolution process which uses autocorrelation function. The well log approach uses the log to determine the constant phase used in combination with statistical approach.

The main objective of wavelet extraction is to obtain qualitative seismic to well calibration. Before we apply seismic to well tie, an accurate depth time conversion was performed in order to make the vertical scale of the well acoustic impedance data match the vertical scale of the seismic data so as to allow spatial correlation [16]. This conversion was carried out using the sonic and the initial two ways travel time. The first sample provides the highest correlation coefficient between the synthetic and the observed trace. This is commonly known as seismic to well tie [17] . In this process, we manually stretch or squeeze the log and the seismic in order to improve the time correlation between the target logs and the seismic attributes. Once the needed bulk shift and stretches are applied, the well log depth to time map match the seismic times. This process simultaneously creates a composite trace from the seismic and synthetics seismogram from the log as shown in Figure 3.

With data properly corrected for error, the well logs were analyzed to determine the hydrostatic pressure trends through points of deviation from the compaction trends of the sediments. The deviations from the compaction trends of the sediments were identified as the point of the overpressure zones. In seismic analysis of overpressure zones, low frequency acoustic impedance model was created [18]. The

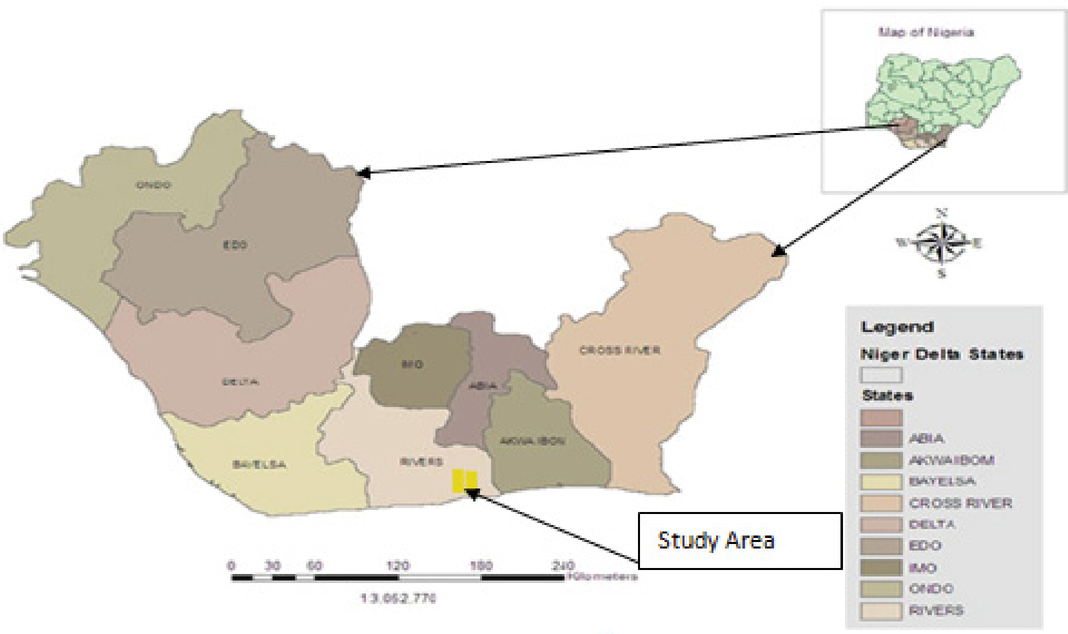

Figure 1: Map of Niger Delta showing the study area.

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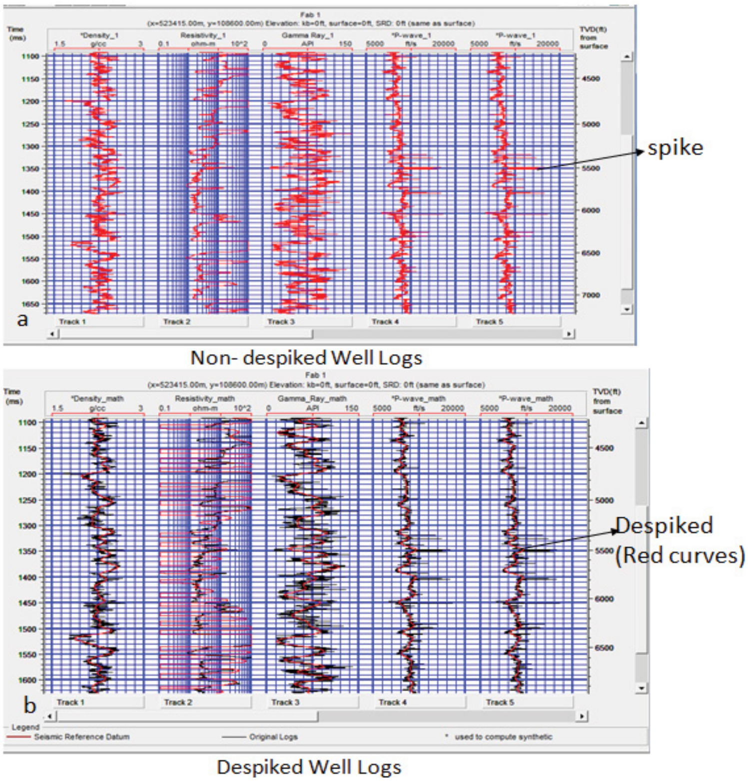

Figure 2: Well log correction showing (a) original well logs with spike and (b) despiked well logs (red curve).

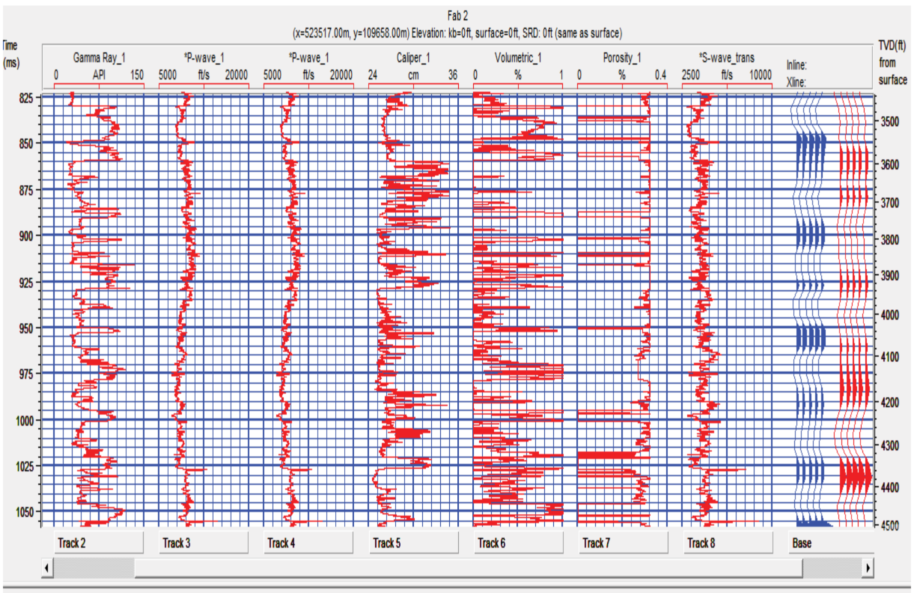

Figure 3: Seismic to well tie of (a) Fabi 1 and (b) Fabi 2.

model based inversion derived the impedance profile which best fit the modeled trace and the seismic trace in a least square sense using initial guess impedance guided by well logs and horizons. Basically this inversion process resolves the reflectivity from an objective function and compares its RMS amplitude with the assumed reflectivity size. The low frequency model was subjected to acoustic impedance inversion. The inverted seismic section in this case, provide means of detecting abnormal pressure regimes by looking at high acoustic impedance zones which may correspond to under compacted shale and hence overpressure zones.

Results and Interpretation

In well log identification of hydrostatic pressure, we exploited the deviation characteristics of rock property from normal compaction trends of both normal and inverted well logs. The pore pressure prediction points were picked from the clean shale depth intervals through the measured points in sands as shown in Figure 4. The well logs exhibited normal compaction trends from depth level of 7200 ft to 8625 ft. At depth level of 8625 ft to 9000 ft, the velocity, density and resistivity logs deviated from the normal compaction trends. This indicates the onset of the overpressure zones.

Sonic velocity increases with depth for a normal pressure zone. It has been observed to follow normal compaction trends. But when overpressure sets in, the velocity invariably slows down and is observed to fall below the normal compaction trend line (blue line). This is due to increase in porosity in the overpressure shale. The depth point where this change begins is known as the top of overpressure. The pink horizontal line highlights the top of overpressure and below it is the overpressure zone as shown in Figure 5. Bulk density measurement is characterized by normal increasing trend until the top of the overpressure zone is reached. In overpressure environments, the bulk density values are lower than normal trend value due to increase pore volume in this zone. However, as rock compacts, porosity is reduced in a normal pressure zones but increase in overpressure zones due to the inability of the pore fluid to escape in equilibrium with the rate of compaction but shale resistivity increases with depth, since porosity decreases due to compaction. In overpressure zones, the resistivity of shale departs from their normal trend, it invariably decreases. This is because of the relative change in the mineralogy whereby the illite part increases at the expense of the montmorillonite part of the clay structure, leading to high conductivity. The red marked horizons on the log suites as shown in Figure 6 identified the reservoir units in across the field identified as sands zones which indicate the measured pore pressure points while the remaining unmarked parts represent the shale units which indicate the predicted pore pressure points with varying vertical depth of occurrence at far right end of the figure

To obtain these depth pressure variations, we introduced crossplots analysis of the predicted pore pressure and measured pore pressure points of study area. However, various mechanisms can cause hydrostatic pressure in rocks and their behavioral pattern differs. With the crossplots of velocity and density logs, two overpressure generating mechanism of the study area were revealed which include undercompaction and unloading mechanism.

The undercompaction is characterized by a linear drop in velocity and increase in density with depth. In this case, with increase in vertical stress, the pore fluids escape as rock pore spaces try to compact. If a layer of low permeability material prevents the escape of pore fluids at rates sufficient to keep up with the rate of increase in the vertical stress, the pore fluids begin to carry a large part of the load and the pore fluid pressure will increase as shown in Figure 7, identified via color codes at far right side of the figure. While unloading is characterized by abrupt decrease in velocity and at constant change in density. In this case, velocity-density plot recognize unloading, characterized by abrupt decrease in velocity at a constant density as shown in Figure 7. Fluid expansion unloading mechanism occurs due to processes like heating, clay dehydration and hydrocarbon maturation (source rock to oil and gas). It could also result when sediment under any given compaction condition has fluids injected into it from a more highly pressure zone. However, in the result of well log inversion, acoustic impedance has a very high degree of correlation to porosity as indicated by well log analysis (Figure 8). An inverted acoustic impedance model of the well log is shown in the red curve while the blue curve represents the original logs. High acoustic impedance represents points of the overpressure which were majorly observed in the shale zones. The horizons defined the net pay cutoffs which relatively aligned with the point of the low acoustic impedance values. The high acoustic impedance is associated with the right kick which probably represent shale zones with high overpressure gradients.

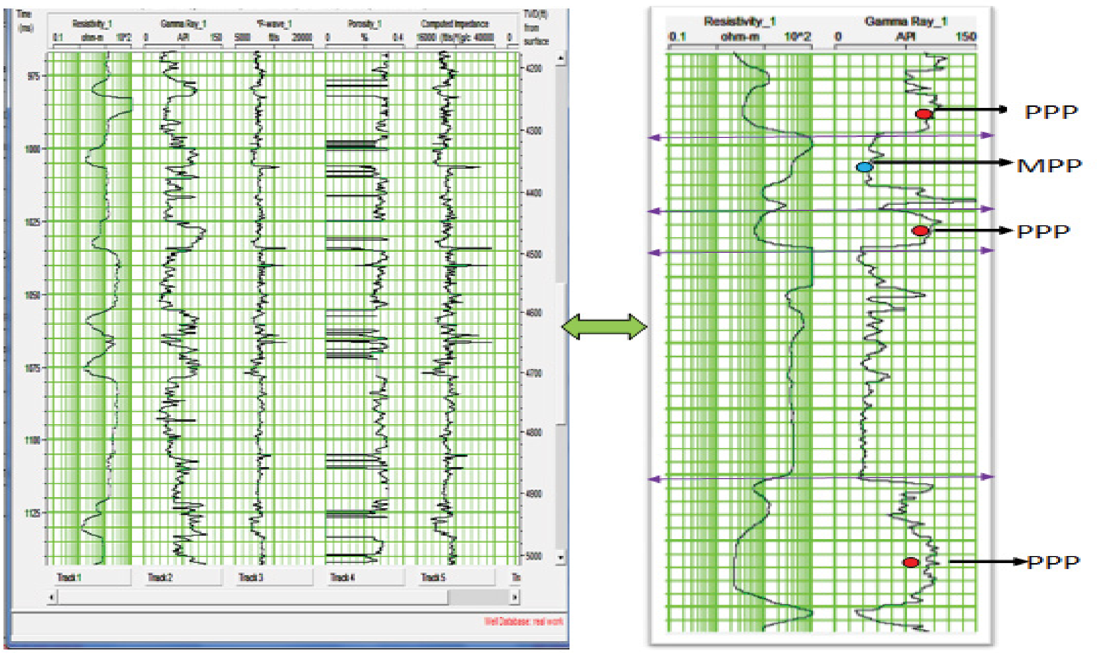

Figure 4: Predicted pore pressure (PPP) points picked from shale depth intervals (red dots) and measured pore pressure (MPP) points in the sands (blue dots).

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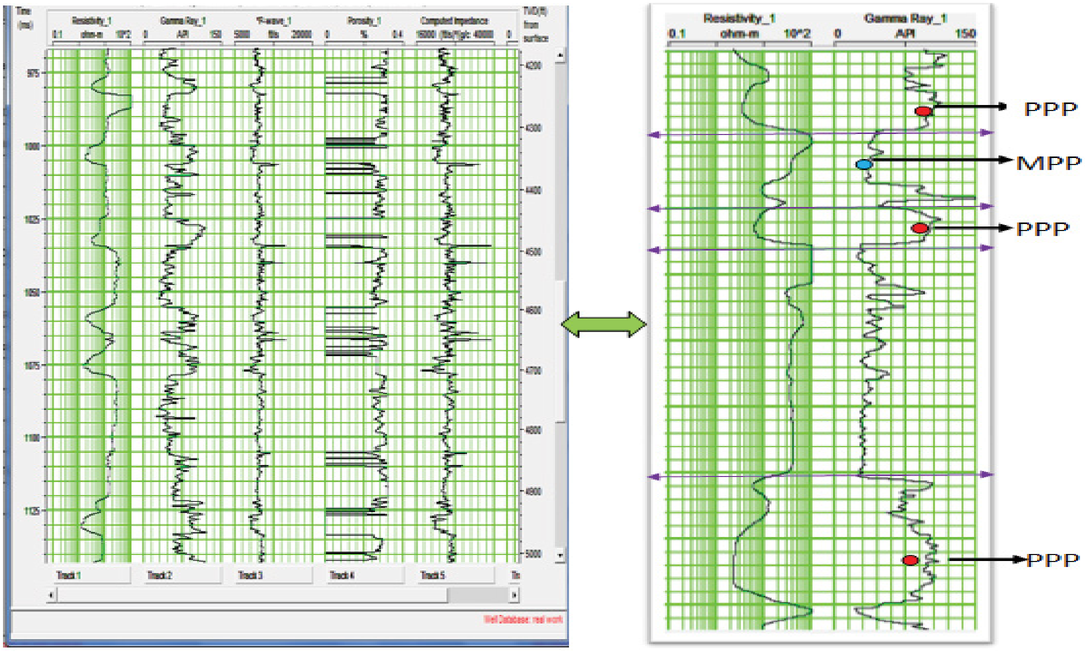

Figure 6: Total vertical stress and normal compaction trend line (blue line) generated from density, P-wave, gamma ray, resistivity, acoustic impedance logs showing onset of overpressure at the normal compaction points of deviations (red line).

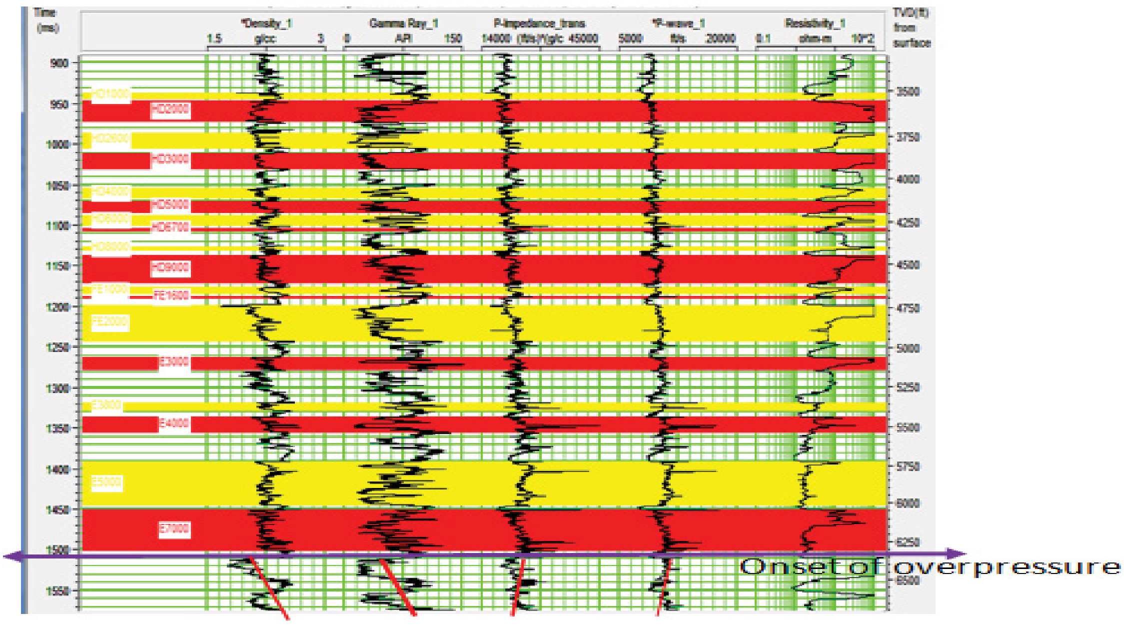

Figure 6: Density, gamma ray, acoustic impedance, P-wave and resistivity logs, showing reservoir horizons and trend line behavioral pattern and deviation indicating overpressure zones.

Well log acoustic impedance inversion presents a clearer picture of overpressure variations in a formation because it correlates the individual points of the pore pressure zones to the seismic data by matching the synthetic of the well logs (red) with that of seismic data (black) as shown in the far right side of Figure 8. To determine the formation overpressure variations, we present acoustic impedance inversion of the seismic data as shown in Figure 9. The results present the hydrostatic pressure zones in the Fabi Field as defined by blue and pink color code which present high acoustic impedance zones in Fabi field. The onsets of over pressure zones are found around 1600 ms to about 1630 ms as indicated by blue color codes. However, very high overpressure gradients occur between 2000 ms to 2100 ms. These zones are characterized by very high acoustic impedance as shown by pink color codes identified via color bar. The result also show high sand/reservoir distributions which are associated

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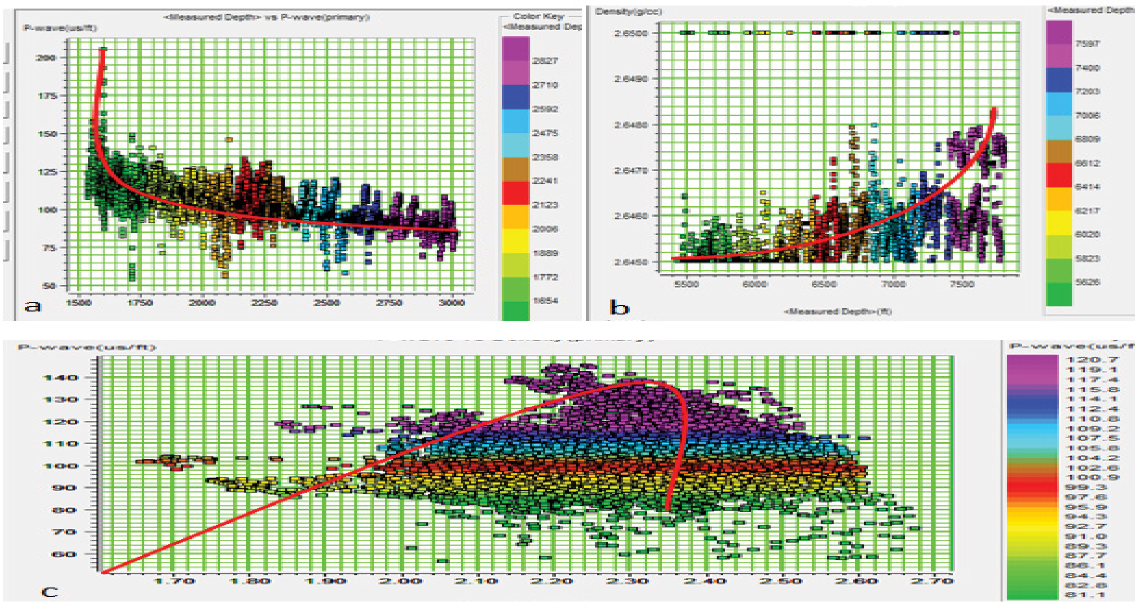

Figure 7: (a) Velocity-Measured depth and (b) Density-Measured depth crossplots recognizing decrease in velocity and increase in density with depth indicating over pressure (identified via color codes) (c) velocity-density plot recognizing Unloading, characterized by abrupt decrease in velocity at a constant density (identified via color codes).

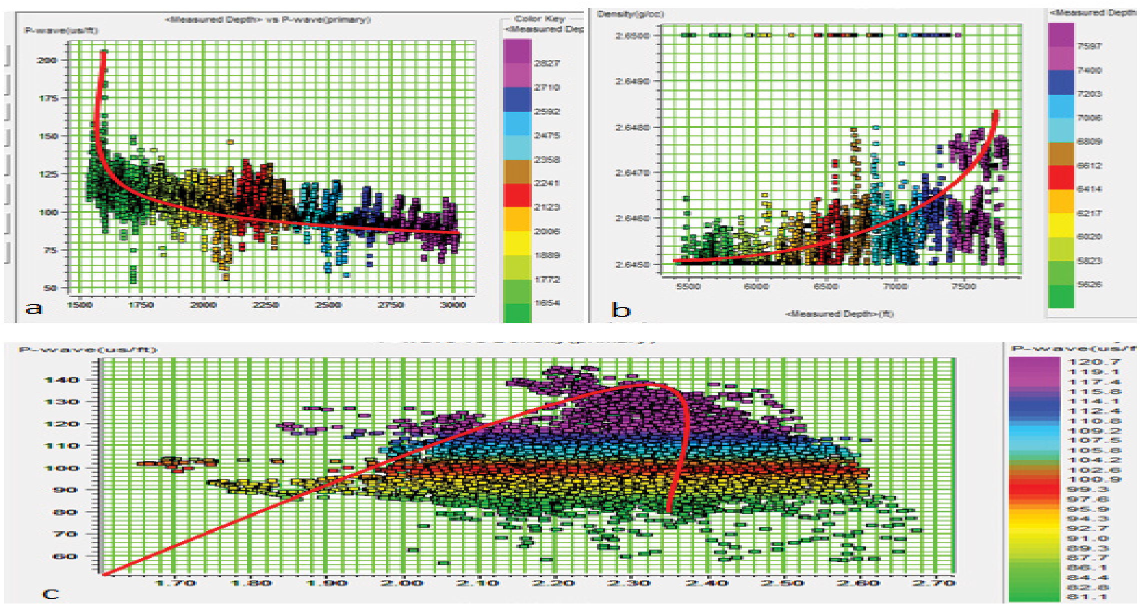

Figure 8: Inverted well log calibrated with synthetic seismic data, starting from 1500-2500 ms. Sands zones are characterized by low acoustic impedance defined by HD horizons indicating reservoir zones while the shale zones are indicated by high acoustic impedance.

with low acoustic impedance as indicated by green and yellow color codes. In acoustic impedance inversion, the area extents of the positive (increase in acoustic impedance) anomalies are mostly consistent with the pressure while low acoustic impedance is interpreted as reservoir or sand zones. However, the analysis of hydrostatic pressure using seismic inversion shows the spatial distribution of the overpressure zones in the study area. The pore pressure monitoring and overpressure detection technique proposed here are based on assumptions on an increase in acoustic impedance techniques. Sand stones reservoir show a negative anomaly (decrease in acoustic impedance) while shale/clay zones are associated with positive anomaly (increase in acoustic impedance). But generally, velocity increases with depth under normal condition of sand homogeneity. Velocity tends to increase with increase in the compaction trends with depth but decreases when it encounters voids which are assumed to be overpressure zones. This assumption was used as a basis for overpressure estimation from well logs. Although we hold this

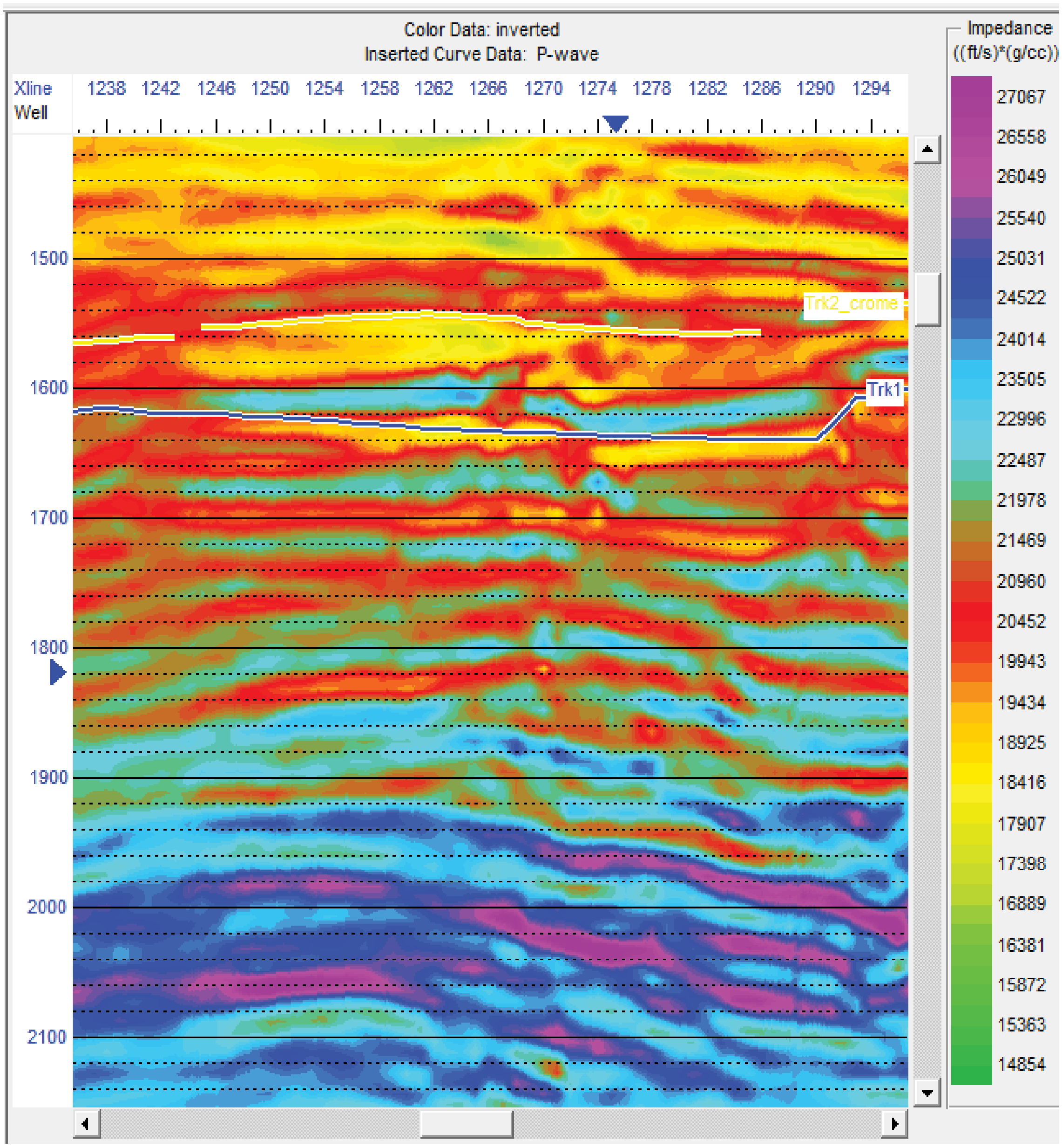

Figure 9: The inverted acoustic impedance volume showing overpressure variations in the field.

assumption not to be always true and this necessitate the use of acoustic impedance inversion in this research. Acoustic impedance uses the relationship between density and velocity to predict the pore pressure variations by conversion of the reflectivity data into quantitative rock properties that are descriptive of Formation.

Conclusion

Well logs and acoustic impedance inversion of Fabi Field, Onshore Niger delta has been studied to understand the hydrostatic pressure variations of the Field. The well logs exhibited normal compaction trends from depth level of 7200 ft to 8625 ft. At depth level of 8625 ft to 9000 ft, the velocity, density and resistivity logs deviated from the normal compaction trends. This indicates the onset of the overpressure zones because as rock compacts, porosity is reduced in a normal pressure zones but increase in overpressure zones due to the inability of the pore fluid to escape in equilibrium with the rate of compaction but shale resistivity increases with depth, since porosity decreases due to compaction. In overpressure zones, the resistivity of shale departs from their normal trend, it invariably decreases. However, with the crossplots of velocity and density logs, two overpressure generating mechanism such as undercompaction and unloading mechanism were revealed. Acoustic impedance inversion revealed the hydrostatic pressure variations of the Field. The onsets of over pressure zones are found around 1600 ms to about 1630 ms. However, very high overpressure gradients occur between 2000 ms to 2100 ms. These zones are characterized by very high acoustic impedance which was identified as high pressure zones.

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