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UNLOADING MECHANISM: AN INDICATION OF OVERPRESSURE IN NIGER DELTA ('X' – FIELD) USING CROSS PLOTS OF ROCK PROPERTIES

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Abstract

This study has investigated the unloading mechanism causes of overpressure and delineated the overpressure zones in X- field Niger Delta. The Niger Delta basin has many overpressure zones with different origins and depositional environments. This research used well log data from four (4) wells in X - Field Niger Delta. The logs include Gamma ray log, deep induction log, Density log, and sonic log. Densities and p-wave velocities derived from sonic log were cross plotted using the *E log* modelling tool embedded within Hampson-Russel software application. The crossplots were subjected to over pressure analysis. The results obtained revealed Unloading mechanism from 5341ft (1627.9m) to 6448ft (1965.4m) and overpressure zones from 4234ft (1290.5m) to 4788ft (1459.4m) about 168.86m thick within well 01, Unloading mechanism from 2289.5m to 2298.3m and overpressure zones from 2280.7m to 2285.1m within well 02, also Unloading mechanism from 3246m to 3335m and overpressure zones observed from 3157m to 3201m within well 03, and finally Unloading mechanism observed from 5970ft (1819.7m) to

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6677ft (2035.1m) and overpressure zones observed from 4554ft (1388.1m) to 5262ft (1603.8m) (about 215.79m thick) within well 04. The results obtained in the over-pressured zones occurred in similar depths in parts of the Niger Delta Basin. The areas identified as overpressure zones should be critically examined prior to drilling to avoid blowout. This study has delineated overpressure zones and unloading intervals in the study area using well logs and crossplots.

Keywords: Overpressure, Compaction, Unloading, Well-Logs, Crossplots.

Introduction

Overpressure zones are major causes of drilling hazards and a key challenge in the exploration and exploitation programme of hydrocarbons reserves. These pressures can sometimes occur in shallow depth of about a few hundred meters (100m) below the subsurface or at depths greater than 6100 meters and can occur in shale/sand sequences and/or carbonate/evaporite sections (Petro-consultants, 1996). Drilling and other well completion operations in the Niger delta could be carried out safely and more cost effectively when an accurate pore pressure prediction is known. In the Tertiary (Onshore) Niger Delta Basin, with high rates of sedimentation and varying geothermal gradients and diastrophic tectonic forces, these factors contribute to subsurface mechanisms of primary disequilibrium from the normal compaction trend and these have not been adequately researched (Hubbert and Ruby, 1959; Yaqub et al., 2013). Pore pressure or formation pressure is the pressure acting on the fluids in the pore space of a formation. This pore fluid pressure equals the hydrostatic pressure of a column of formation water extending to the surface and is termed Normal pressure. Hydrostatic pressure is controlled by the density of the fluid saturating the formation. However, as pore water becomes saline, or other dissolved solids added, the hydrostatic pressure gradient will increase, so also will sonic velocity, density and resistivity of a normally pressured formation will increase with depth of burial and the way such rock properties vary with burial under normal pore pressure conditions is termed its normal compaction trend (Bowers 2002).Overburden pressure is the pressure that results from the combined weight of the rock matrix and the fluids in the pore-space overlying the formation of interest. This pressure increases with depth and is also called the vertical stress.Effective pressure is the pressure acting on the solid rock framework. Terzaghi (1939) defined it as the difference between the overburden pressure and the pore pressure. Effective pressure thus controls the compaction that takes place in porous granular media including sedimentary rocks and this has been confirmed by laboratory studies (Dvorkin et al., 1999). Any process or condition causing a reduction of effective stress will result in overpressure. In overpressured formations, the pore fluids bear part of the weight of the overlying rocks. A lower effective stress and a higher porosity tend to lower the rock velocity. Consequently, a relationship between velocity and effective stress, porosity and lithology could be used to study pore pressures(Bell 2002).

Unloading Mechanism is a secondary pressure mechanism that occur on top of primary compaction and undercompaction processes (Chopra and Huffman, 2006). The term unloading is used because it tends to cause the in-situ pore pressure to increase by reducing the effective stress on the rock matrix. Unloading is identified by the reduction in effective stress as the pore pressure increases rapidly under specific conditions (Chopra and Huffman, 2006). Overpressures in sedimentary basins is caused by different mechanisms, but the key causes are those related to increase in stress and in-situ fluid generation. During deposition of sediments, as vertical stress increases, pore fluids escape as pore spaces are lost to compaction. If a layer of low permeability (clay) prevents the escape of pore fluids at rates proportional to the rate of increase in vertical stress, the pore fluid begins to carry a large part of the load and pore-fluid pressure will increase. This process is referred to as undercompaction or compaction disequilibrium (Hubbert and Rubey, 1959), and is by far the most well understood overpressure mechanism used to explain overpressures in Tertiary basins where rapid deposition and subsidence occur such as the Niger Delta basin (Omudu*et al.*, 2012). Being unaware of the genesis of overpressure is a key reason why pore pressure prediction can go wrong (Bower, 1995).

Geologic Setting

The Niger Delta is situated on the Gulf of Guinea in the West coast of Africa. It is located at the southeastern end of Nigeria, bordering the Atlantic Ocean and extends from Latitude 4^0 to 6^0 North and Longitude 3^0 to 9^0 East. The tectonic framework of the Niger Delta is related to the stresses that accompanied the separation of the African and south American plates (as proposed by Alfred Wegner), which led to the opening of the South Atlantic. The Niger Delta Basin is the largest sedimentary Basin in Africa with an area of about 75,000km^2, and a clastic fill of about 9,000 to 12,000m (30,000 to 40,000ft) and terminates at different intervals by transgressive sequences (Stacher, 1995). The proto Delta developed in the Northern part of the Basin during the Campanian transgression and ended with the Paleocene transgression. Sedimentary deposits in the Basin have been divided into three large-scale lithostratigraphic units namely: (a) the basal Paleocene to Recent pro-delta facies of the Akata Formation. (b) Eocene to Recent paralicfacies of the Agbada Formation and (c) Oligocene to Recent, fluvial facies of the Benin Formation (Short and Stauble, 1967; Evamy et al, 1978 and Whiteman, 1982). These formations became progressively younger into the basinward, recording long-term progradation (seaward movement) of depositional environments of the Niger Delta into the Atlantic Ocean Passive Margin. The stratigraphy of the Niger Delta is complicated by the syn-depositional collapse of the clastic wedge as shale of the Akata Formation mobilized under the load of prograding deltaic Agbada and fluvial Benin Formation.

Overpressures in the Niger Delta have attracted the attention of operators and researchers quite early into the Oil and gas development activities in the basin where the depth of penetration of exploration wells were determined by the occurrence of first kicks in such wells. This practice seemed to be borne out of the belief that the occurrence of first kicks should mark the onset of overpressure hence the termination of drilling (Nwozor*et al*, 2013). However, with precautionary increases in mud weight, target depths were often achieved with many of such wells erroneously classified as non-overpressuredbased on where no kicks have been experienced. Earlier studies relied on the kicks data and reversals in log trends to develop a series of pressure graphs and rudimentary maps aimed at delineating the onset of overpressures and their distribution in the basin, based on convictions that undercompaction was the cause of the overpressures. Most of these maps and accompanying data were however not published.

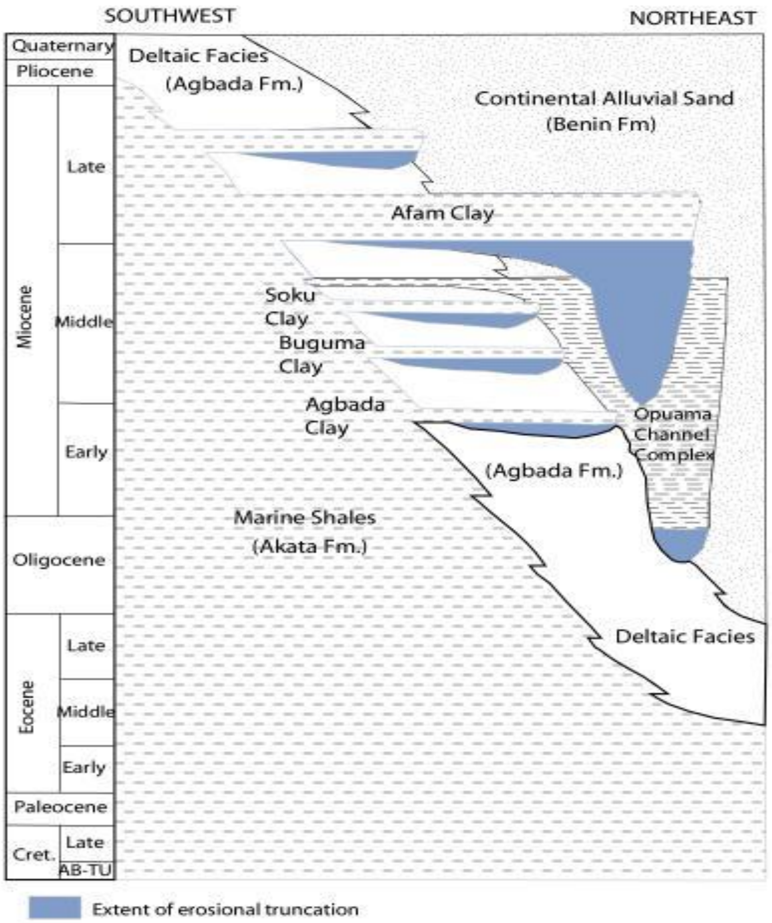

Figure 1: Stratigraphic column of the Niger Delta (Modified from Doust and Omatsola, 1989).

Materials and Method

The data used in this work includes well log data (Gamma ray, Density and Sonic logs) from suites of four (4) wells from onshore and offshore parts of the Niger Delta Basin. Wells (02 and 03) are from an onshore Oil field while two other wells (01 and 04) are from an offshore Oil field. The well data were randomly picked to ensure that the results can be used in quantifying the field and the Niger Delta Basin at large. The data provided was in Ascii format. The analysis was done within Hampson Russell Software (HRS) application using three (3) major steps: Well-log editing and modelling, well log cross plotting and interpretation. Hampson Russell Software consists of several modules, some of which includes the Geoview module, which serves as a starting point of any Hampson Russell program. Well log data were imported and loaded into Geoview well database through the Well Explorer file.

The E logis the well log editing and modelling tool embedded within the Hampson-Russel software suite of applications. It is started from Geoview and used to edit and average logs. Cross plots of Velocity (derived from sonic log) versus depth, and Velocity versus density were made and overpressure zones of interest were defined from the cross plots, which were projected back into the input logs to visualize its equivalent depth.

Using Microsoft excel Programme, Velocity (V) was computed from sonic log using the equation below:

Velocity in meters per second (V) = $(10^6/\Delta T) *0.3048$………………………………. (1)

where:

10^6 = a constant for converting from microseconds to seconds,

ΔT = Sonic log value (Interval transit time in microseconds per feet),

0.3048 = a constant for converting feet to meters.

Cross plots are visual representations of the relationship between two or more variables, and they are used to visually identify or detect anomalies which could be interpreted as the presence of hydrocarbon or other fluids and lithologies. Cross plot analysis was carried out to determine the rock properties / attributes that better discriminate the reservoir (Omudu*et al*., 2007).

Results

The results of this research are presented in Figures 1 - 13. The cross plots analyses are useful in delineating the unloaded zones. Unloading intervals were delineated from the Velocity-Density crossplotssince density increases with depth in the subsurface. If this is true, rock velocity will equally increase with depth (due to vertical stress and compaction) and as such, the crossplots of density vs velocity will keep increasing with depth or follow a regular normal trend. The unloading intervals were established at points where the crossplots had double irregular departure from the normal trend.

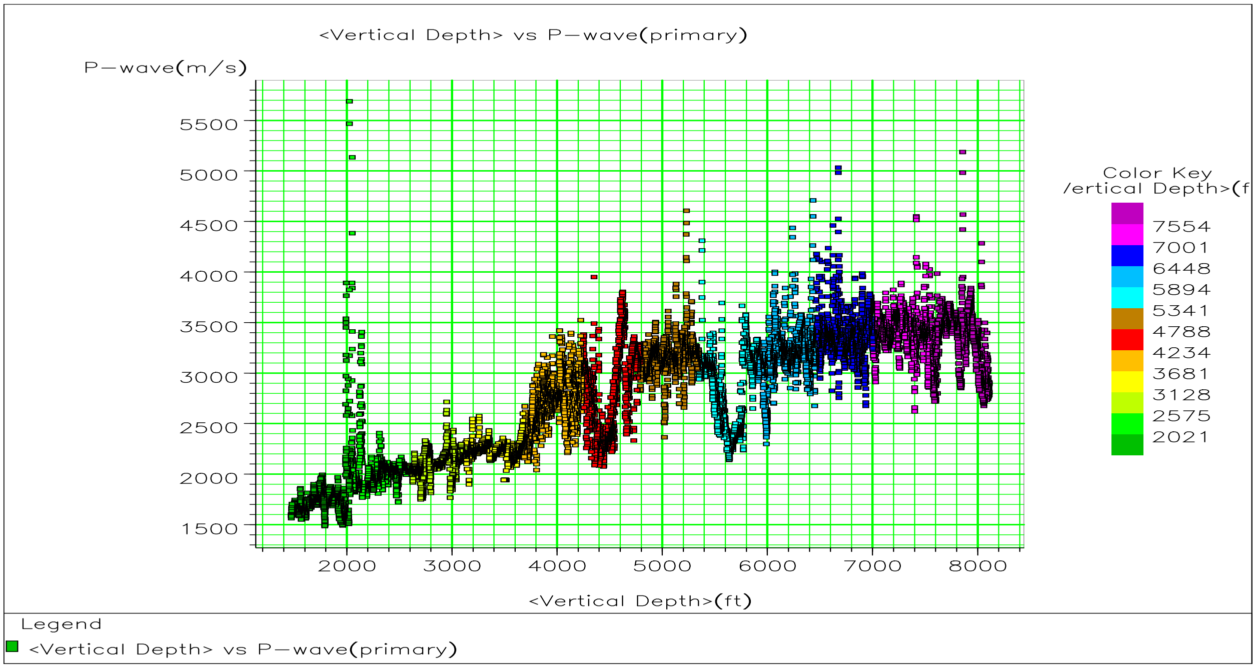

Figure 2: Velocity vs Depth plot for well 01. Velocity increased with depth in the normal trend.

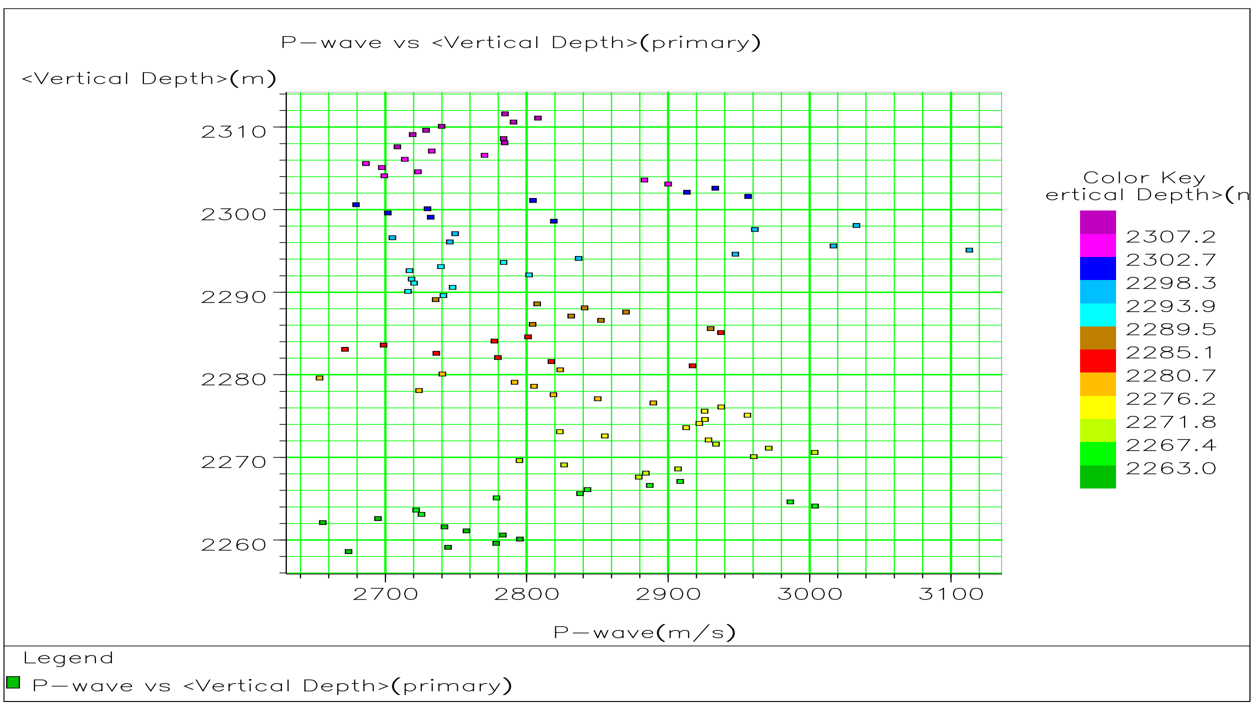

Figure 3: Velocity-Depth plot for well 02. Velocity increased but the trend is not linear.

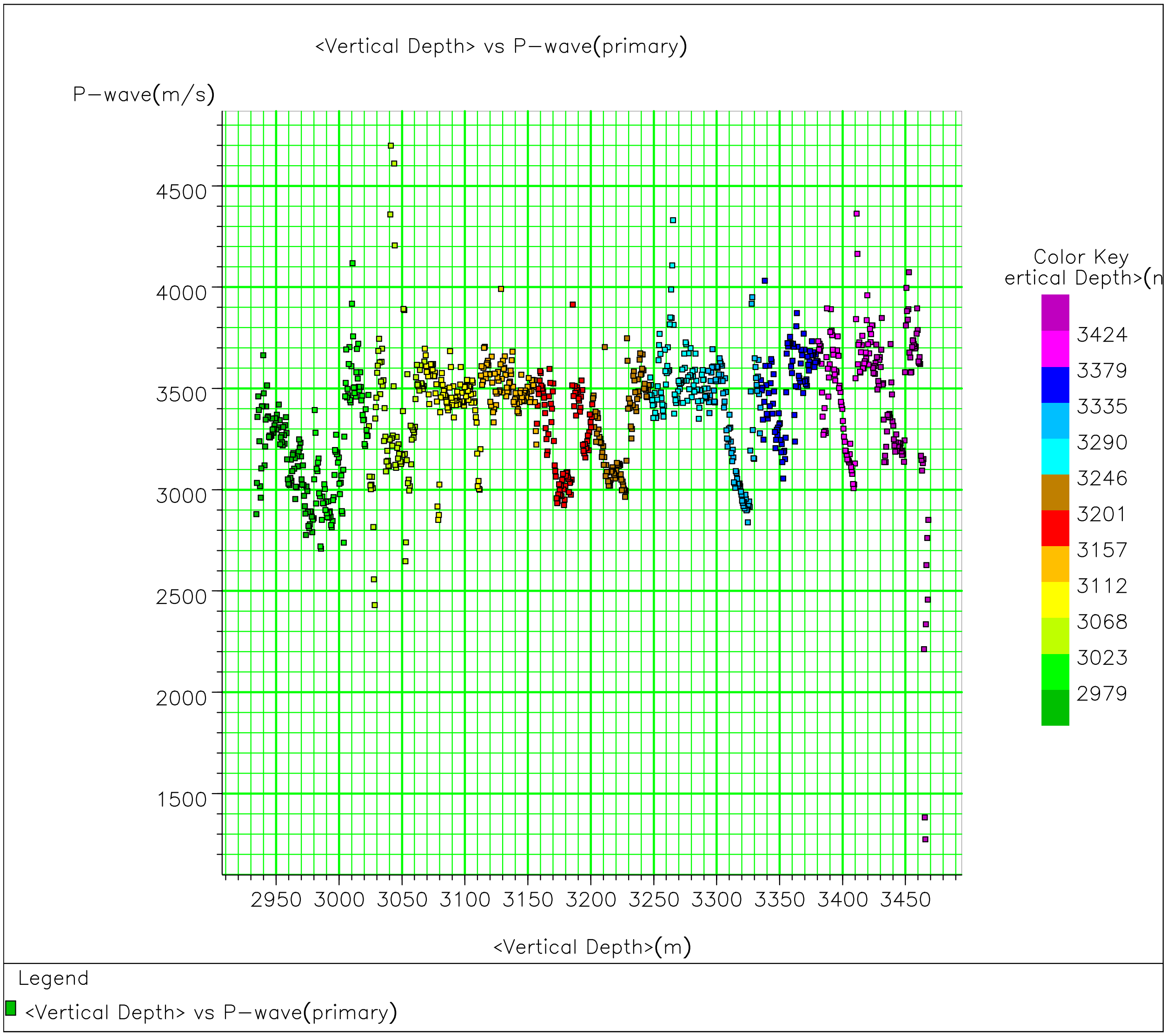

Figure 4: Velocity-Depth plot for well 03. Velocity increased slightly with and remained steady with depth.

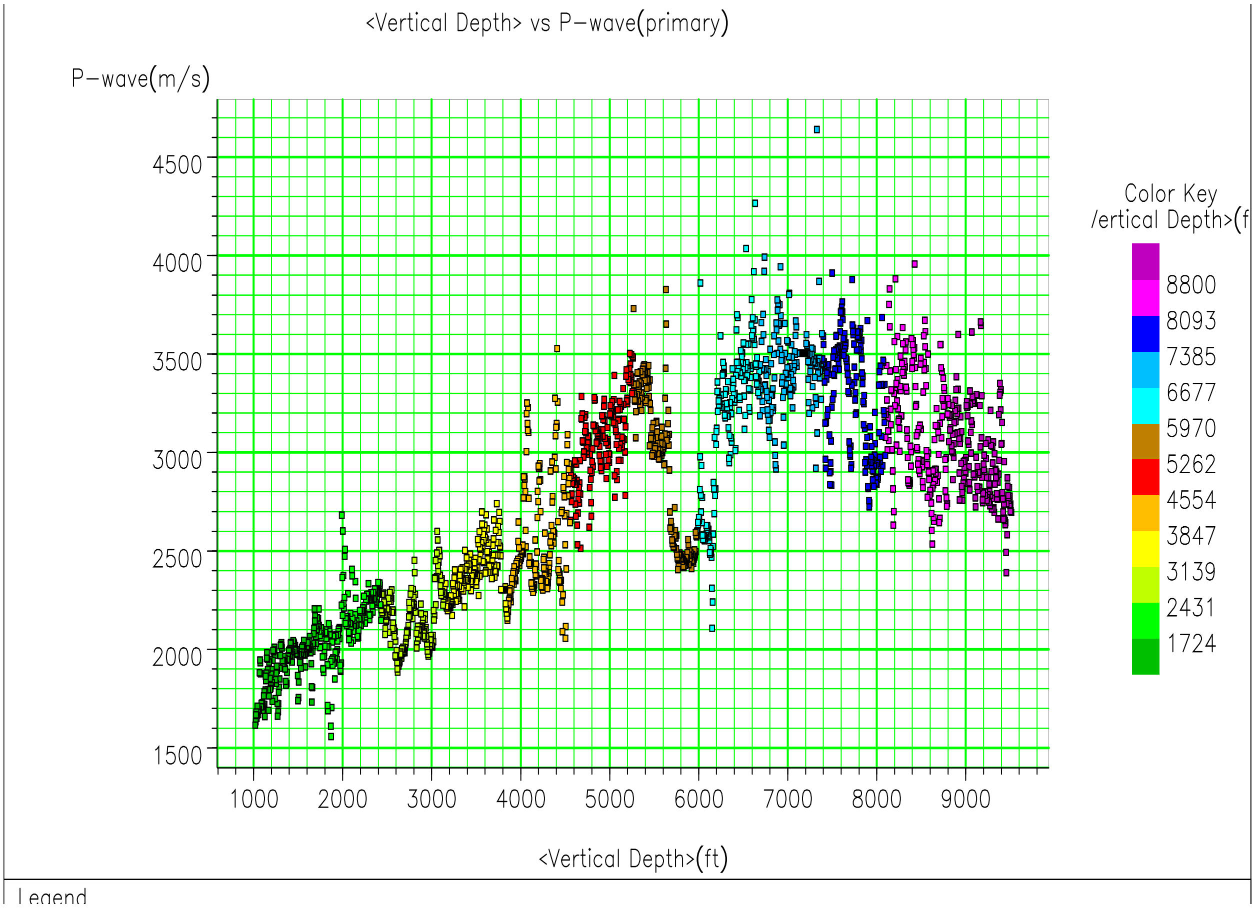

Figure 5: Velocity-Depth plot for well 04. Velocity increased and dropped.

The plots presented above (figure 2 to 5) were arrived at using Geoview software. The same procedure was repeated using Microsoft Excel and the results are presented below;

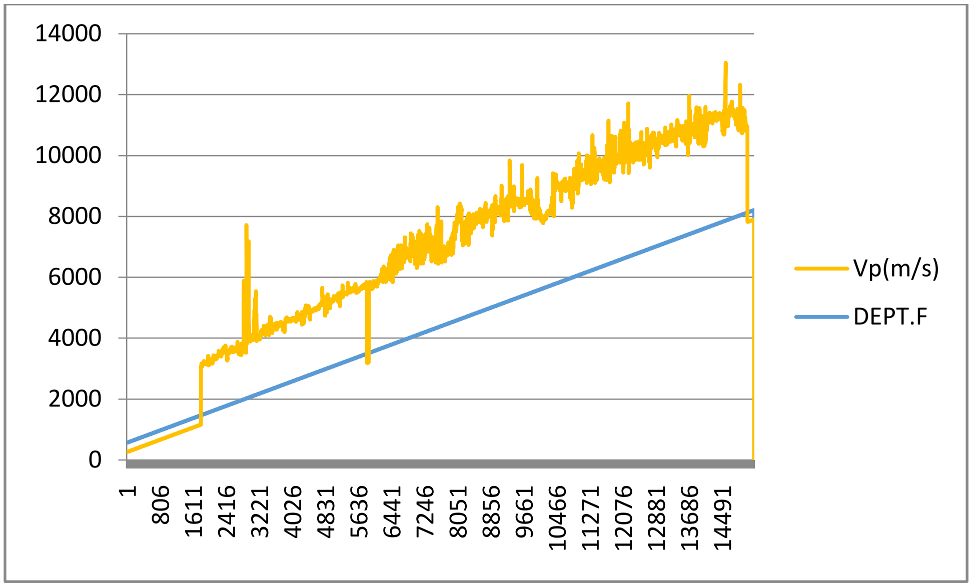

Figure 6: Velocity-Depth plot for well 01 from Excel

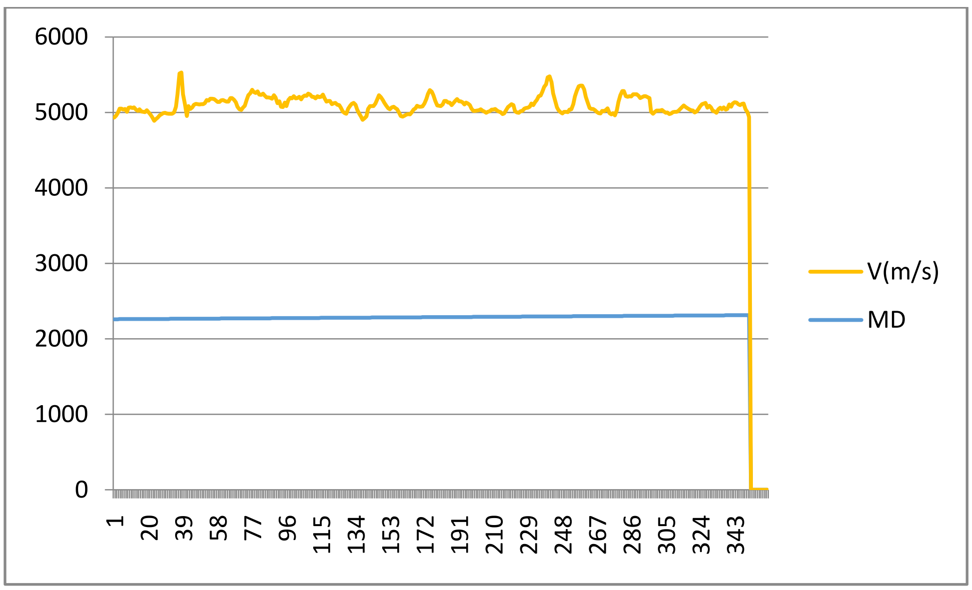

Figure 7: Velocity-Depth plot for well 02 from Excel

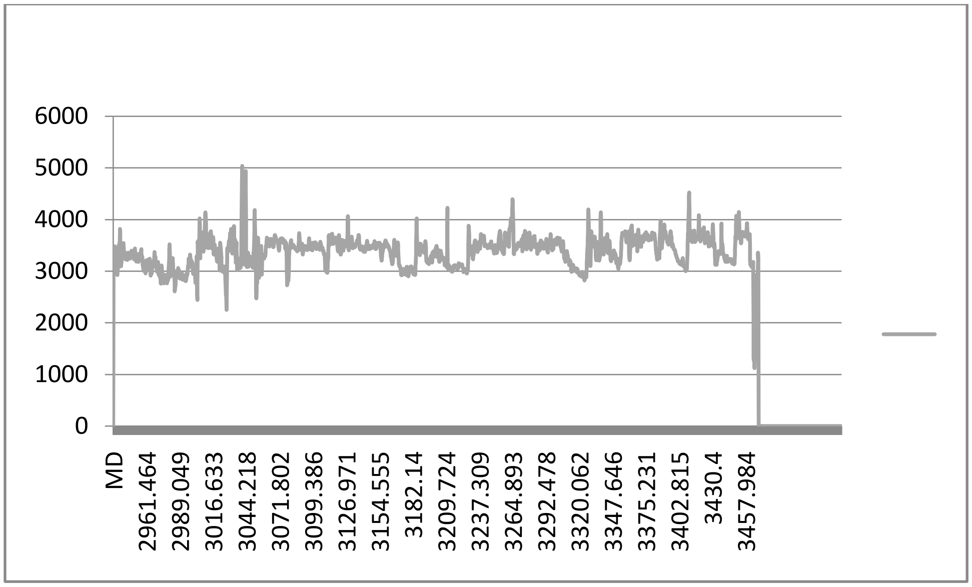

Figure 8: Velocity-Depth plot for well 03 from Excel

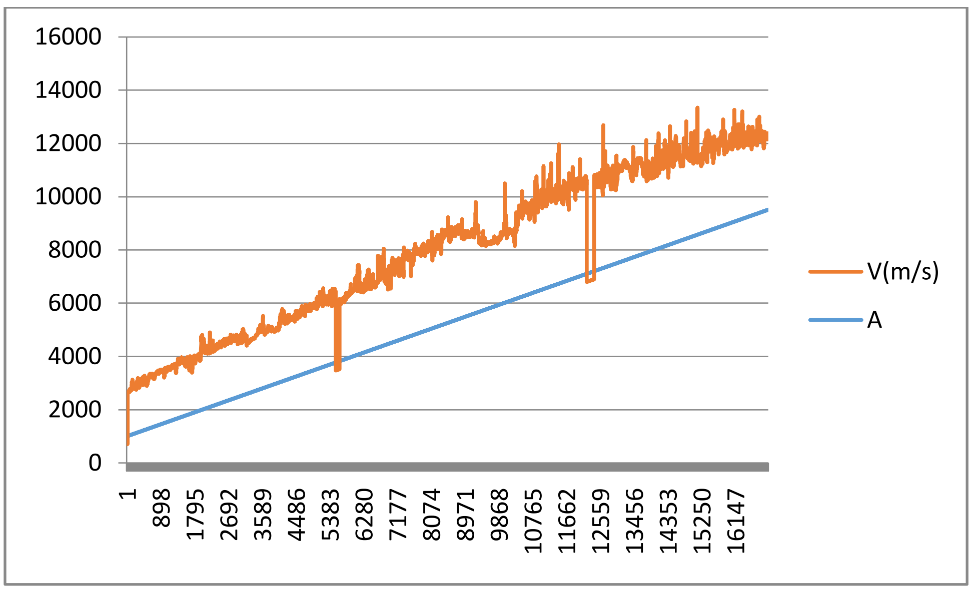

Figure 9: Velocity-Depth plot for well 04 from Excel

The values of velocity gotten from Sonic logs were cross-plotted against the values of Density gotten from density logs to delineate Unloading and the results are presented below.

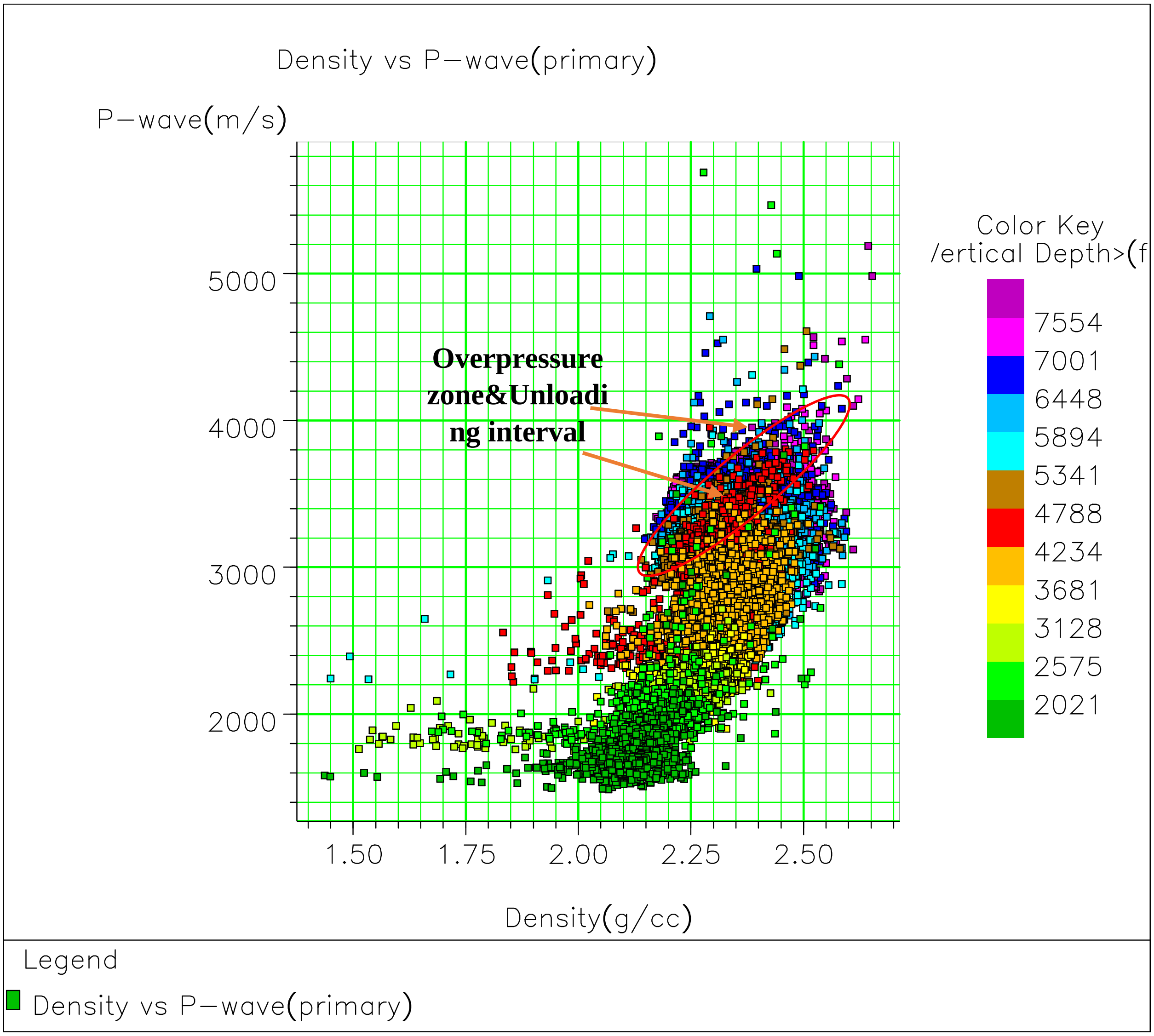

Figure 10: Velocity vs Density cross-plot for well 01. Unloading interval is seen from 5341ft to 6448ft (about 337.4m thickness), and Overpressure zones occurred from 4234ft to 4788ft about 168.86m thick (Shown by the red ellipse).

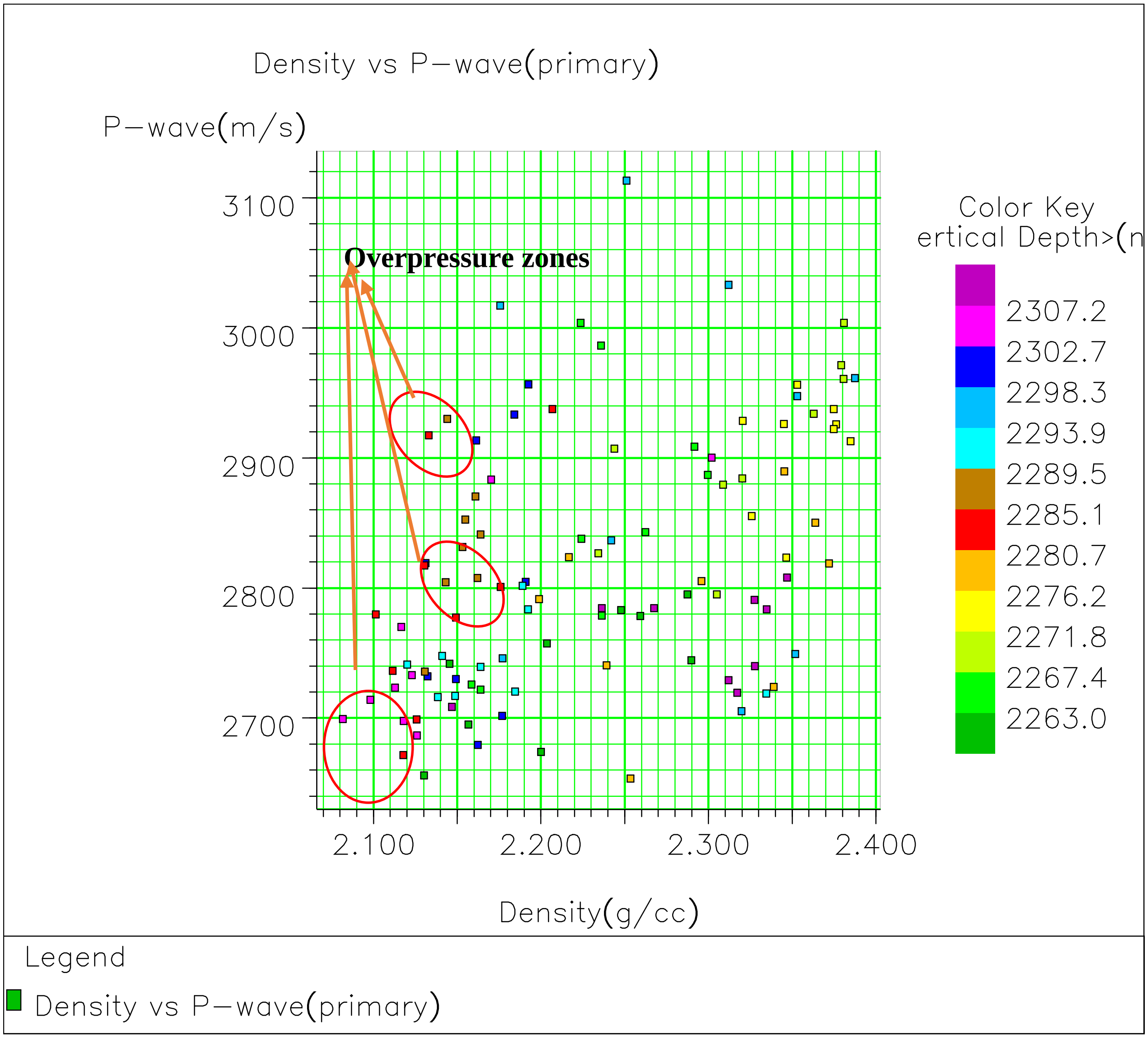

Figure 11: Velocity vs Density cross-plot for well 02. Unloading mechanism is observed from 2289.5m to 2298.3m (blue colour key), while overpressure zones occurred from 2280.7m to 2285.1m (red colour key).

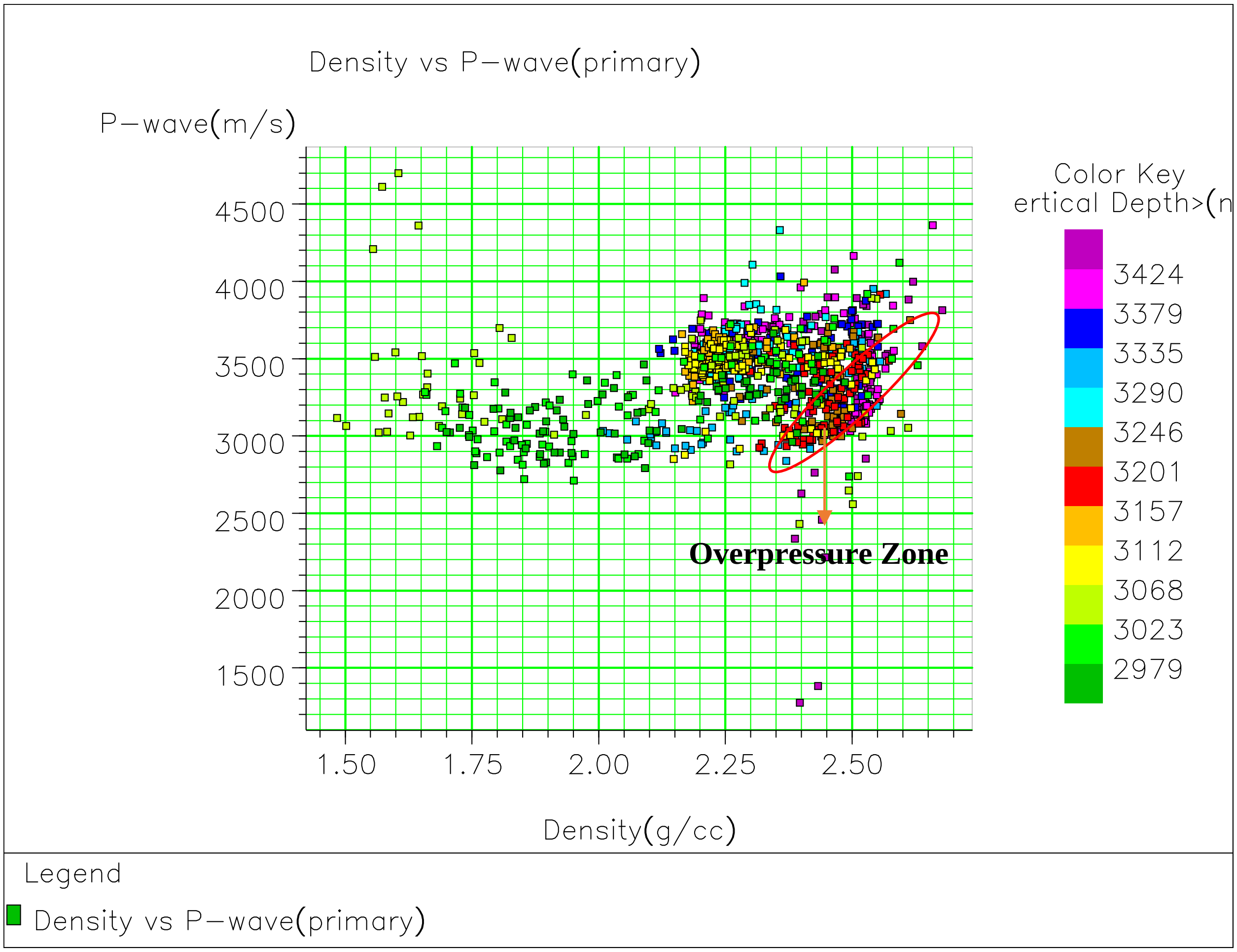

Figure 12: Velocity vs Density cross-plot for well 03. Unloading mechanism occurred from 3246m to 3335m (about 89m thick), while overpressure zones is observed from 3157m to 3201m (red colour key) and about 44m thick.

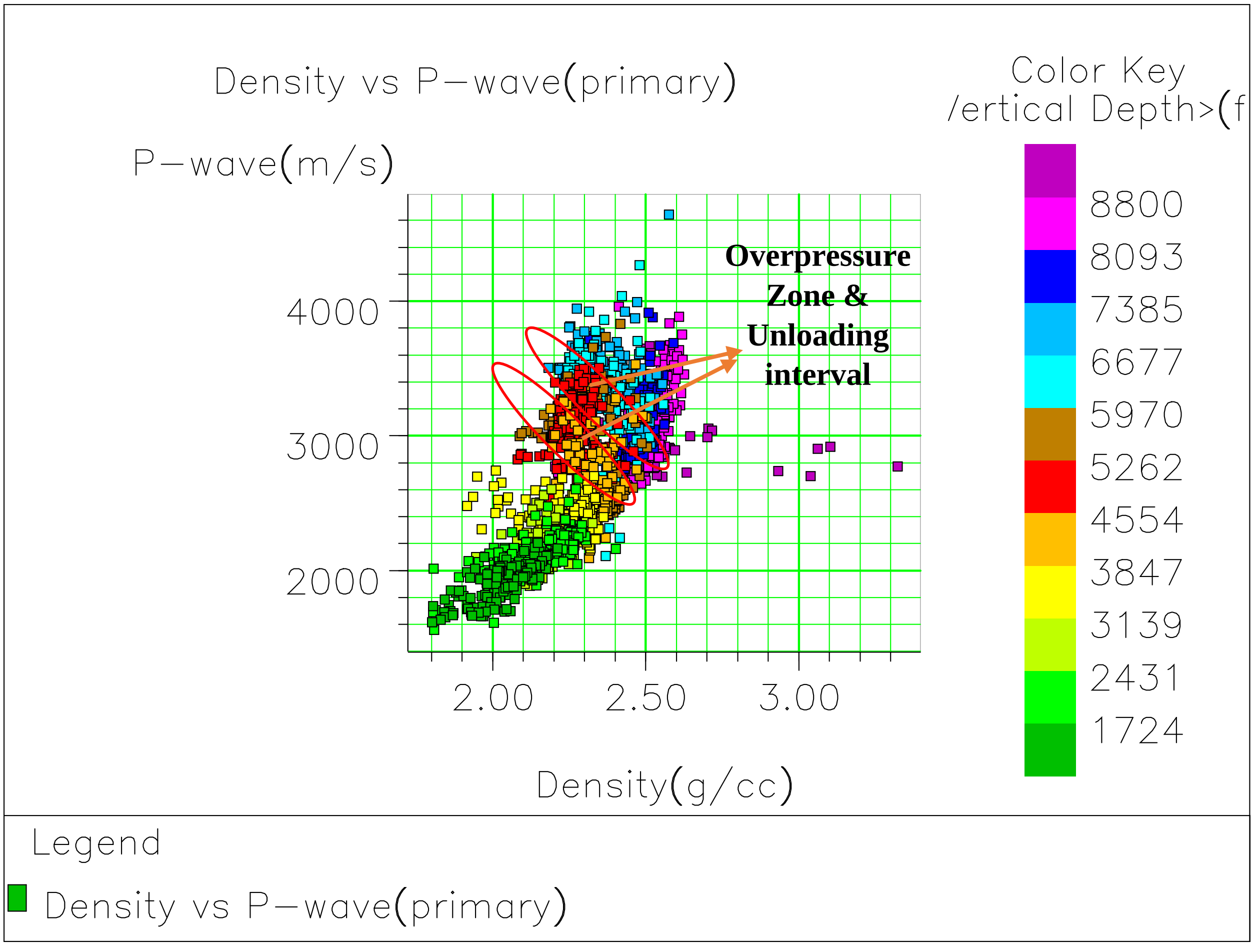

Figure 13: Velocity vs Density cross-plot for well 04. Unloading mechanism is observed from 5970ft to 6677ft (about 215.49m thick), while overpressure zones is observed from 4554ft to 5262ft (about 215.79m thick).

Analysis and Discussion

WELL 01(figure 10): Top of overpressure zone (denoted by red on the depth color key) observed showed density dropping from 2.46g/cc at 4131ft and velocity of 3098.34m/s through 2.06g/cc at 4192ft at velocity of 2574.79m/s to 1.83g/cc at 4280ft at velocity of 2553.29m/s and 1.89g/cc at 4503ft to velocity of 2411.86m/s, (figure 10). Velocity decreased from 3620.49m/s at 4637.5ft to 2392.93m/s at 4657ft and density decreased from 2.5g/cc to 2.29g/cc within the same depths.

Overpressure zone (denoted by red on the depth color key) was delineated from 4234ft to 4788ft while 5341ft to 6448ft and marked as the unloading interval were velocity which decreased from 3379.62m/s at 5451ft to 2378.92m/s at 5548.5ft.

WELL 02 (Figure 11): The overpressure zones (denoted by red on the depth color key) was delineated between 2280.7m and 2285.1m while Unloading intervals were observed between 2289.5m and 2298.3m. Within these intervals, density dropped from 2.35g/cc to 2.1g/cc, whereas the velocity as observed was steady at some intervals and later fluctuated and dropped from 2959.22m/s to 2660m/s within these intervals.

WELL 03 (figure 12): Overpressure zones (denoted by red on the depth color key) was delineated at 3157m and 3201m while Unloading mechanism was observed between 3246m and 3335m. Density dropped from 2.5g/cc to 1.95g/cc at 3317.9m and continued to fluctuate between high and low values and later rose to 2.5g/cc at 3322.7m. Within these intervals, velocity first remained steady and later dropped from 3725.6m/s to 2822.74m/s at 3324.78m before rising to 4194.88m/s at 3327.98m whereas the density was about 2.59g/cc. High density values is between 2.4g/cc and 2.59g/cc while low density values was between 1.9g/cc and 2.2g/cc.

WELL 4 (figure 13): Overpressure (denoted by red on the depth color key) was observed between 4554ft and 5262ft. It started from 4484.5ft (as evident in the velocity-depth relationship) where density dropped from 2.4g/cc at 4576ft to 1.94g/cc at 4770ft. Velocity also dropped from 3105.77m/s at 4753.5ft to 2625.1m/s at 4791ft. Unloading mechanism was observed between 5970ft and 6677ft as evident in the velocity-density cross-plot.

Conclusion

The investigated unloading mechanism Indications of overpressure using crossplots of density versus velocity for four (4) wells in the Niger delta basin. These plots delineated overpressure zones at different depths within the study area. Comparisons were made between the results obtained, and the result of crossplots to delineate secondary pressure mechanisms in Jean-Pierre *et al.*, (2002), and results of density vs velocity crossplots made for wells (01, 03, and 04) agrees with other works. In addition, density vs velocity crossplots for well 02 corresponds to the results of Bowers (2002), where he likened the unloading interval to a trajectory. The results from the density vs velocity cross-plot shows that overpressure begin at 4234ft (1290.52m) for well01 and 4554ft (1388.06m) for well04 in offshore Niger Delta (X-field). These intervals are very close in value with the intervals of overpressure in the Niger Delta by Nwozor*et al.*, (2013) at 4494ft

(1370m). This suggests that Density versus Velocity cross plot can provide insight into the genesis of overpressure in the Niger Delta basin which might have been caused by disequilibrium compaction of sediments.

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