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Research paper

Quantitative prediction of overburden pressure and overpressure zones using well logs - a case study of an x-field in the Niger-delta basin, Nigeria

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Abstract

Prediction and evaluation of overburden pressure are critical for the exploration and production of hydrocarbon reservoirs. Overburden pressure was estimated using well log (density and sonic) data obtained from two wells (B1 and B2) of an X - Field within the Niger Delta basin. Overburden pressure depends primarily on the bulk density data. Bulk density was extracted from density and sonic logs based on the log signatures. The bulk density was then used to determine overburden pressure using Eaton's equation. The results reveal that overburden pressure increases linearly with depth, and an overburden gradient of 1.0 psi/Ft. was obtained. The overburden pressure was used to estimate pore pressure and vertical effective stress and thus enabled the determination of overpressure zones within the well.

Keywords: *Overburden Pressure; Over Pressure Zones; Pore Pressure; Vertical Effective Stress; Niger Delta.*

1. Introduction

Overburden pressure is the stress imposed on a layer or rock by weight of overlying material (Eaton, 1997). It is known to occur worldwide due to mechanical compaction of sediments. During sedimentation, shale and sands compact as the layer of sediments is overlain by younger rocks, this causes a reduction of thickness, loss of porosity and in-situ water as the weight of overburden rocks increases. The overburden pressure gradient is a measure of the change in overburden pressure exerted on the underlain rock by the overlain rock as a function of depth (Terzaghi, 1967). The gradient varies as a function of compaction and depth of burial. Comprehensive knowledge and the ability to predict overburden pressured formations are of direct concern in the exploratory and development phases of the well life (Huffmann, 1976). The reasons for this prediction include assessing the vertical effective stress and the pore pressure of a formation which can equally be used to predict abnormal pressures in a formation.

The primary objective of this paper is to use an integrated technique to determine overburden pressure from both density and sonic (Acoustic logs) and subsequently use this to determine over-pressured zones within the wells for optimal field development planning.

2. Geologic settings of the Niger delta basin

The present field is located within the Niger-Delta Basin (Figure 1). This basin is situated at the southern end of Nigeria boarding the Atlantic Ocean and extends from about Longitude 30° 00'E to 9° 00'E and Latitude 4° 3' N to 5° 20' N (Lambert, 1981).

It is the youngest sedimentary basin within the Benue through a system. Three litho-stratigraphic units are distinguishable in the Tertiary Niger Delta. The Akata formation which is predominantly marine pro-delta shale is overlain by the paralic sand/shale sequence of the Agbada Formation. The upper most sections are the continental upper deltaic plain sands – the Benin formation. Virtually, all the hydrocarbon accumulations in the Niger Delta occur in the sands and sandstones of the Agbada formation. The overburden rock of the Niger delta complex consists of the Benin formation and variable proportions of the Agbada formation. Under normal conditions, the Niger delta has an overburden pressure gradient of 1.0 psi/ft. and a pore pressure gradient of 0.465 psi/ft. (Powler, 1990).

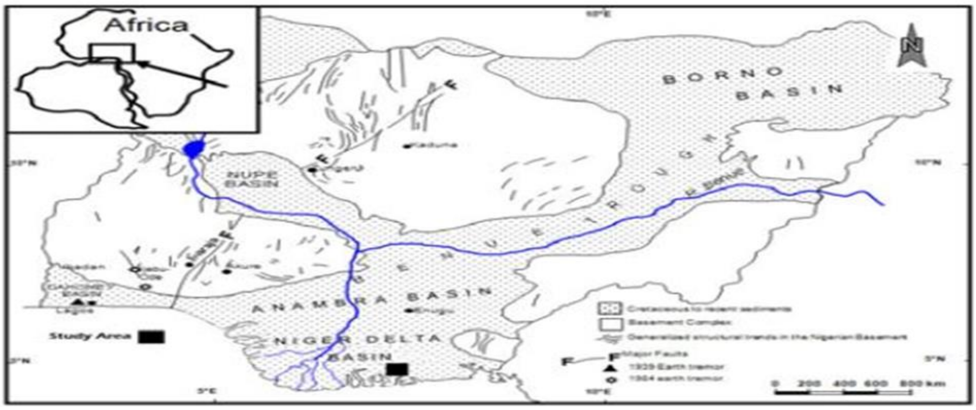

Fig. 1: Generalized Geologic Map of Nigeria Showing the Study Area (Odeyemi Et Al., 1999).

3. Materials and methods

The data used for the study consist of well logs, predominantly density and sonic logs, both from which bulk density values were extracted.
Overburden pressures (Povb) at different depths, D were calculated using Eaton's equation, 1968.

$$P_{ovb} = \rho_{bulk} \text{ x } D \text{ x } 0.433 \quad (1)$$

Where Povb= overburden pressure, D = depth; 0.433 = conversion factor from g/cm3 to psi and ρ_{bulk} = the bulk density which is a measure of the weight of rock and pore fluids.
Overburden pressure gradient (Govb); given the overburden pressure, the overburden pressure gradient which is the overburden pressure at each particular depth was determined from equation (2)

$$Govb = P_{ovb}/D \quad (2)$$

Where Govb = Overburden gradient (psi/m), P_{ovb} = Overburden pressure (psi), D = depth (meters).
The overburden gradient obtained from equation (2) in psi/m was converted to Psi/ft. by dividing with a conversion factor of 3.2808.

$$Govb\ (psi/ft) = P_{ovb}/\ (3.208)\ (psi/m) \quad (3)$$

Where Govb = overburden gradient
Pore pressure gradient (P) was calculated using the equation by Terzaghi, 1953.

$$P = Govb - \sigma_v \quad (4)$$

Where P = pore pressure gradient, Govb = overburden pressure gradient and σ_v = vertical effective stress gradient

Vertical effective stress gradient (σ_v) was calculated using equation 5.

$$\sigma_v = 1 - \mu \quad (5)$$

Where µ is the Poisson ratio and

µ= -1.882 × 10^-10(H) + 7.2947129 × 10^-6 (H) + 0.4260341387

And H = depth (ft.)

3.1. Determination of overburden pressure using density Log

a) Bulk density (ρ_{bulk}) values were extracted at different depths in meters from the density log signatures running through the well from depth intervals of 2000m to 3100m.
b) Overburden pressure was then calculated at different depths by substituting bulk density values into equation (1).

3.2. Determination of overburden pressure using sonic Log

a) Sonic travel times (µs/m) were extracted at different depths in meters from the sonic log signatures running through the well from depth intervals of 2000m to 3100m.
b) The sonic travel time in (µs/m) was then converted to velocity in (m/sec) using the conversion factor of equation 6.

$$\text{Velocity (m/sec)} = 10\ 6 / \text{travel time } (\mu s/m) \quad (6)$$

c) Determination of bulk density from Gardener's equation(1974) shown below;

$$\rho_b = 0.31V0.25 \quad (7)$$

Where ρ_b = Bulk density (g/cm^3); V = Velocity (m/s)
d) Determination of overburden pressure at a different depths using equation (1).

4. Results and discussion

This study identified zones of overpressures in the wells considered. A combination of basic input parameters; sonic logs, and density logs were used to generate sonic travel times, overburden pressure trends, overburden pressure gradient, pore pressure gradient, and pore pressure trends.

4.1. Overburden pressure computation for Well B-1

Table-1A (refer to Appendix) shows sonic travel time, velocity, bulk density and overburden pressure, computed from depth of 2000m to 3100m from sonic log.
Table-1B (refer to Appendix) shows the depth, bulk density and overburden pressures computed from depth of 2000m to 3100m from the density log.
Figure-2A below shows a plot of depth versus overburden pressure obtained from well B-1 using sonic log. The graph trend shows that overburden pressure increases with depth.
Figure-2B below shows a plot of depth versus overburden pressure obtained from well B-1 using density log. The graph trend shows that overburden pressure increases with depth.

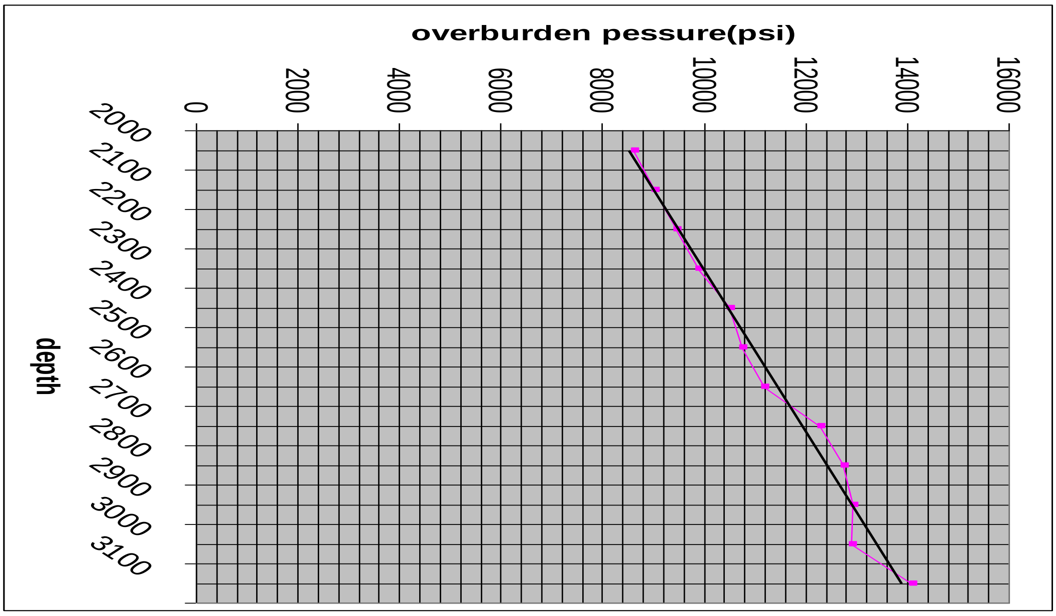

Fig. 2: A) Plot of Depth against Overburden Pressure from Sonic Log in Well B-1.

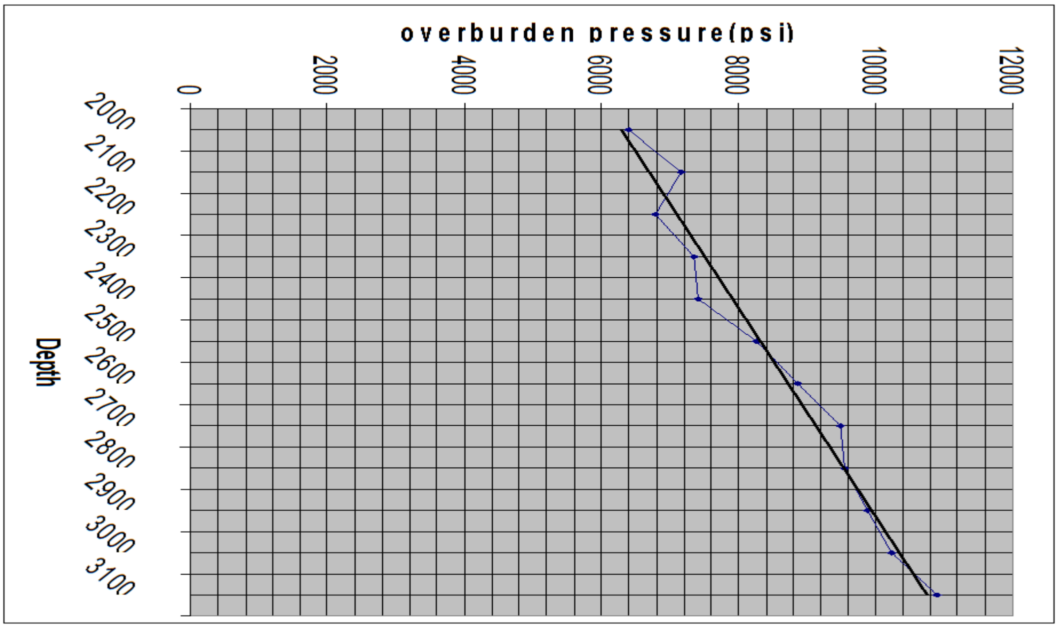

Fig. 2: B) Plot of Depth Against Overburden Pressure from Density Log in Well B-1.

4.2. Overburden pressure computation for Well B-2

Table-2A (refer to Appendix) shows sonic travel time, velocity, bulk density and overburden pressure, computed from depth of 2000m to 3100m.

Table-2B (refer to Appendix) shows the depth, bulk density and overburden pressures determined from the density log of well B-1. Bulk density and overburden pressure are computed from depth of 2000m to 3100m

Figure-3A shows a plot of depth versus overburden pressure from well-B2 using sonic log. The graph trend shows that overburden pressure increases with depth.

Figure-3B shows a plot of depth versus overburden pressure obtained from well-B2 using density log. The graph trend shows that overburden pressure increases with depth.

4.3. Calculating overburden pressure gradient

Using equation (2), the overburden gradient (psi/m) and overburden gradient (psi/ft.) of both the sonic and density log in well B-1 (Table 3A) and well B-2 (Table 3B) are calculated and presented (refer to appendix). A depth interval of 2000m – 3100m was sampled. The overburden gradient calculated to indicate values of close to 1.0 psi/ft. on the average especially that of the density log, while that of sonic log averages 1.3 psi/ft.

Table-3A (refer to Appendix) shows the depths, overburden pressure, overburden pressure gradient (psi/m & psi/ft) of both the density and sonic logs in well-B1.

Table-3B (refer to Appendix) shows the depths, overburden pressure, overburden pressure gradient (psi/m & psi/ft) of both the density and sonic logs in well-B2.

4.4. Calculating pore pressure gradient

Table-4 (refer to Appendix) shows depth, Poisson ratio, pore pressure gradient, and pore pressures for Well-B1 and Well-B2.

Figure-4A shows a plot of pore pressure vs. depth obtained for well-B1.

Figure-4B shows a plot of pore pressure vs. depth obtained for well-B2.

Using equation (4), Pore pressure gradient was determined for both wells B-1 and B-2 and presented in table 4 (refer to Appendix). Results from all the wells indicate the presence of over pressured zones, and even zones characterized with certain degrees of under pressures. The plot of depth against pore pressure (Figure-4A & Figure-4B) indicates the onset of overpressure at about 2450m (7800ft) to 2550m for well B-1 and 2450m to 2750m for well B-2 respectively. As observed in Figure-4A and Figure-4B, the normal compaction trend-line shows a shift at these depths. Pressure values obtained, ranges from 3000psi to 5800psi for well B-1 and 2500psi to 5200psi for well B-2. An average formation pressure gradient of about 0.5 psi/ft. was observed, and this is classified as mild overpressure.

The result shows that predicted pressures in well – B1 (Figure 4A) begins to move away from normal hydrostatic line and deviate from the normal compaction trend-line at depth of 2450m, signifying the onset of overpressure. Formation pressure gradient averaging about 0.4 psi/ft. is observed, which is mildly over-pressured. From 2450m to 3100m, formation pressure gradient of 0.5 psi/ft. is then observed.

The results show that Well –B2 (Figure 4B) is characterized with mild overpressure at depths of 2200m and pressure gradient of 0.4 psi/ft. High overpressure sets in at 2500m with an average pore pressure gradient of 0.5 psi/ft. from 2500m to 3000m.

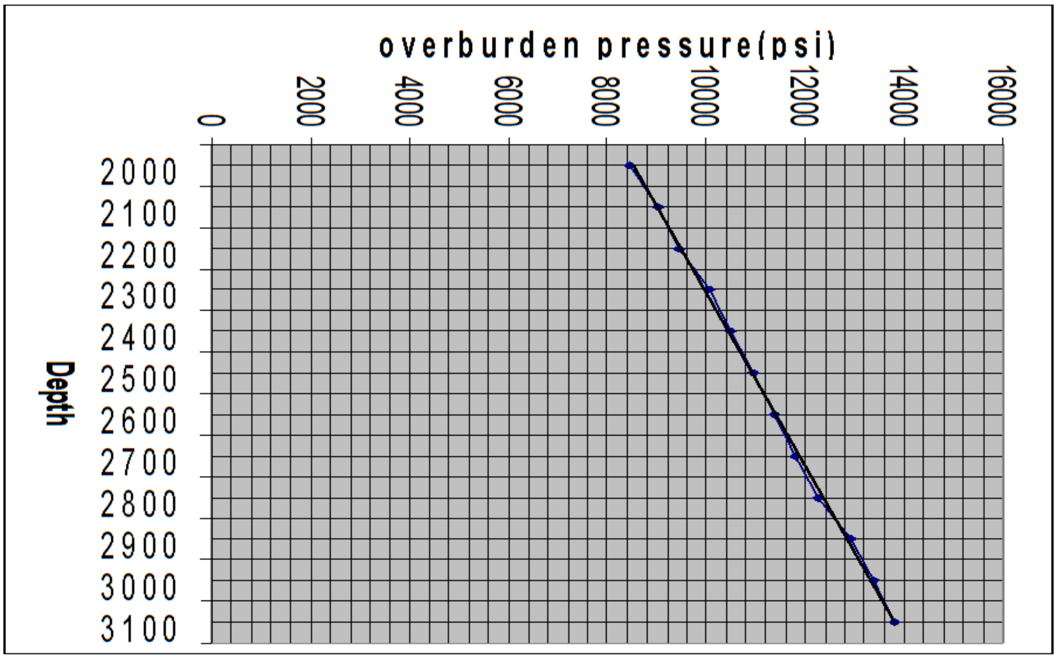

Fig. 3: A) Plot of Depth against Overburden Pressure in Well B-2 Using Sonic Log.

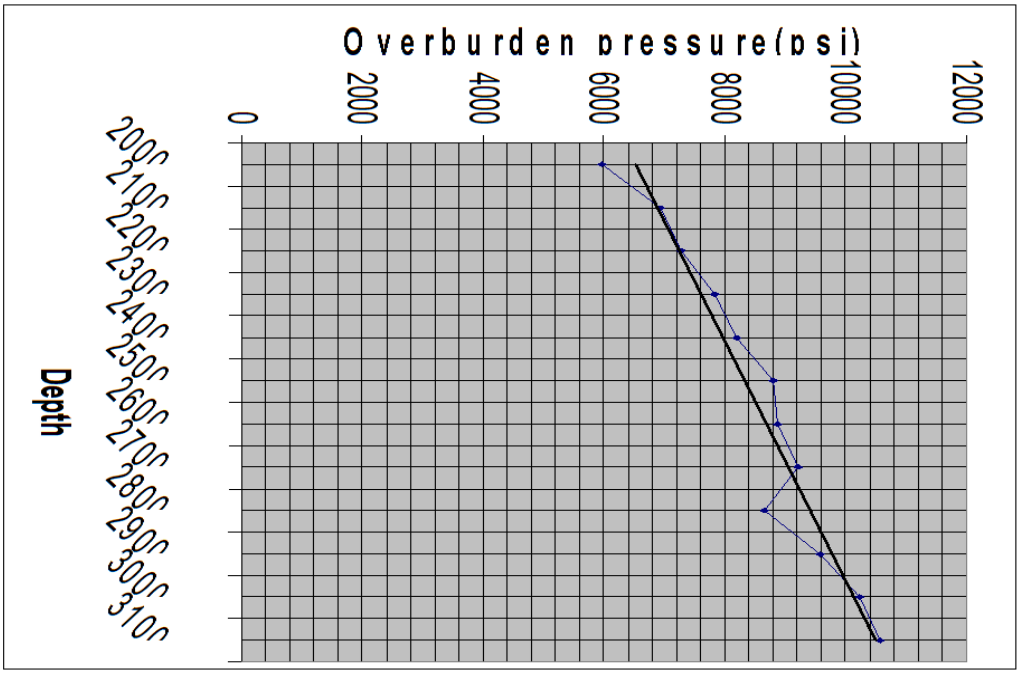

Fig. 3: B) Plot of Depth against Overburden Pressure in Well B-2 Using Density Log.

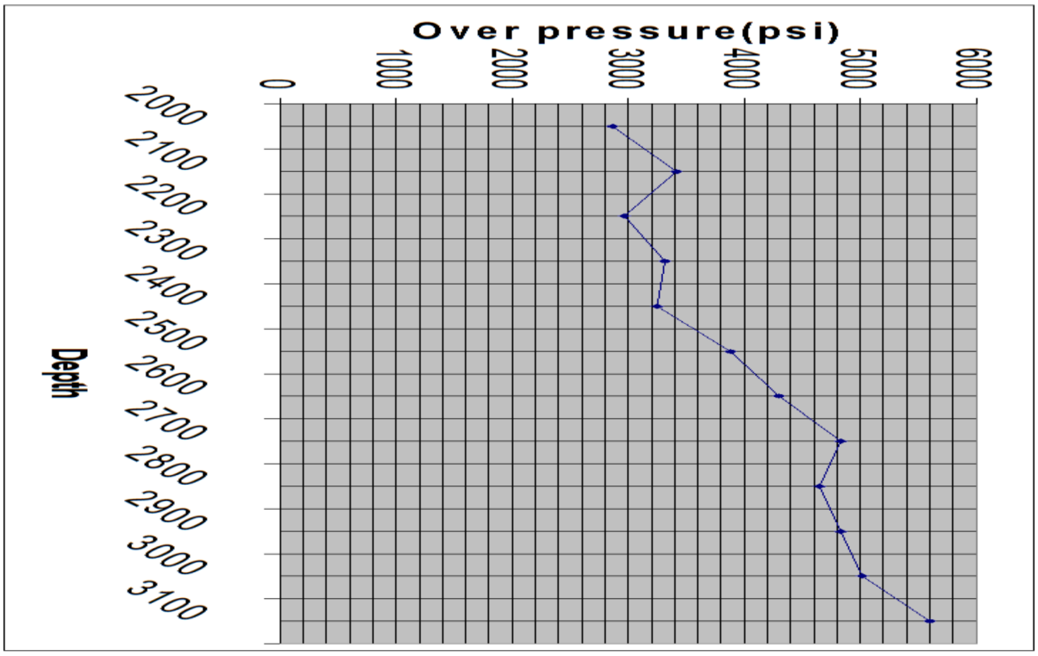

Fig. 4: A) Plot of Pore-Pressure against Depth and Overpressure Estimation for Well B-1.

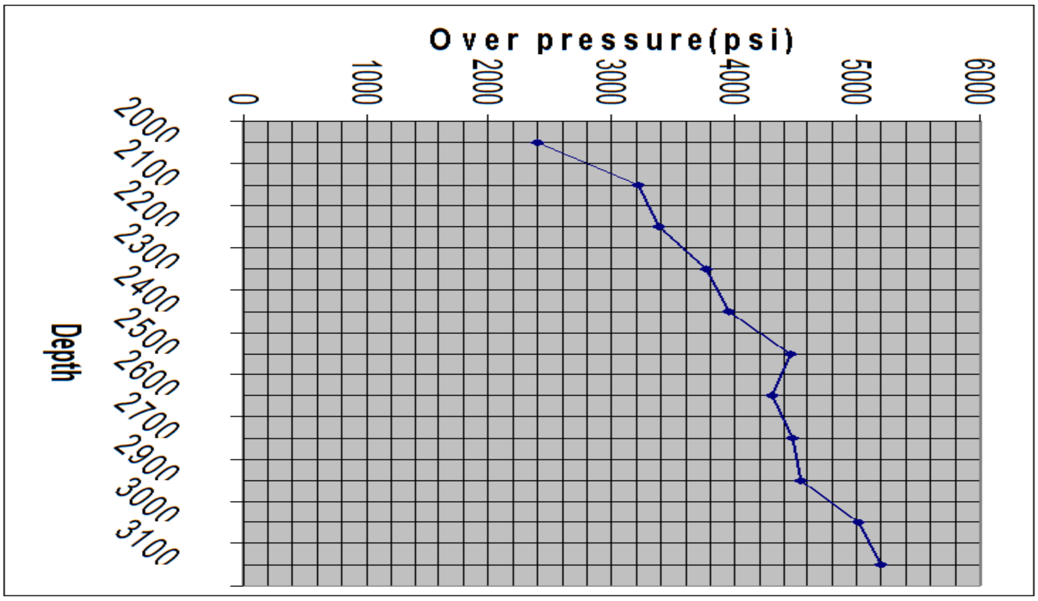

Fig. 4: B) Plot of Pore-Pressure against Depth and Overpressure Estimation for Well B-2.

5. Conclusion

We used bulk density extracted from both density and sonic logs to estimate overburden pressures and overpressure zones of two wells (B1 and B2). There is a slight disagreement between density values obtained with sonic and density logs. This leads to a slight difference in the overburden pressures, and overpressure estimated from both logs.

Overburden gradient estimated from the density log is very close to the value of 1.0 psi/ft., which is the average values of the overburden gradient obtained within the Niger-delta region, indicating that density logs are better overburden pressure prediction tools than sonic logs.

Overpressure estimations were carried by observing the deviations of the predicted fluid pressures from the hydrostatic pressure line. The results obtained from the analysis reveal that the two wells are mildly over pressured at near-same depths. 2450m for wellB-1 and 2500 for wellB-2 (Figure 4A and Figure 4B).

Since bulk density is critical for overburden pressure determination, the best source of bulk density data is from in- situ measurement made from a density log.

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Appendix:

Table 1: A) Overburden Pressures Obtained From Sonic Log in Well B-1

Depth (m)	Sonic travel-time (us/m)	Velocity (m/sec)	Bulk density (g/cm3)	Overburden pressure (psi)
2000	110.22	9072.76	3.025	8594.63
2100	110.22	9072.76	3.025	9024.36
2200	110.22	9072.76	3.025	9454.09
2300	110.22	9072.76	3.025	9883.82
2400	102.692	9737.86	3.079	10497.66
2500	110.22	9072.76	3.025	10743.28
2600	110.22	9072.76	3.025	11173.02
2700	87.637	11410.71	3.20	12273.98
2800	87.637	11410.71	3.20	12728.57
2900	95.165	10508.06	3.138	12927.74
3000	110.22	9072.76	3.025	12891.94
3100	87.637	11410.71	3.20	14092.35

Table 1: B) Overburden Pressures Obtained from Density Log in Well B-1

Depth (m)	Bulk density (g/cm3)	Overburden pressure (psi)
2000	2.25	6392.7
2100	2.4	7159.82
2200	2.175	6797.57
2300	2.25	7351.60
2400	2.175	7415.53
2500	2.325	8257.24
2600	2.4	8864.54
2700	2.475	9493.16
2800	2.4	9546.43
2900	2.4	9887.38
3000	2.4	10228.32
3100	2.475	10889.55

Table 2: A) Overburden Pressures Obtained from Sonic Log in Well B-2

Depth (m)	Travel-time (us/m)	Velocity (m/sec)	Bulk-density (g/cm3)	Overburden pressure (psi)
2000	117.74	8492.78	2.975	8452.57
2100	110.22	9072.76	3.025	9024.36
2200	110.22	9072.76	3.025	9454.09
2300	102.69	9737.86	3.079	10060.26
2400	102.69	9737.86	3.079	10497.66
2500	102.69	9737.86	3.079	10935.06
2600	102.69	9737.86	3.079	11372.47
2700	102.69	9737.86	3.079	11809.87
2800	102.69	9737.86	3.079	12247.27
2900	95.165	10508.06	3.138	12927.74
3000	95.165	10508.06	3.138	13373.52
3100	95.165	10508.06	3.138	13819.31

Table 2: B) Overburden Pressures from Density Log in Well B-2

Depth (m)	Bulk density (g/cm3)	Overburden pressure (psi)
2000	2.1	5966.52
2100	2.325	6936.07
2200	2.325	7206.36
2300	2.4	7841.7
2400	2.4	8182.65
2500	2.475	8789.96
2600	2.4	8864.54
2700	2.4	9205.48
2800	2.175	8651.45
2900	2.325	9578.39
3000	2.4	10228.32
3100	2.4	10569.26

Table-3: A) Overburden Gradient in Well B-1 Using Density and Sonic Logs

Depth (m)	Sonic Log over-burden pressure (psi)	Sonic Log Overburden gradient (psi/m)	Sonic Log Overburden gradient (Psi/ft.)	Density Log over-burden pressure (psi)	Density Log Over-burden gradient (psi/m)	Density Log Over-burden gradient (Psi/ft.)
2000	8594.63	4.297	1.31	6392.7	3.1963	0.97
2100	9024.36	4.297	1.31	7159.82	3.4094	1.03
2200	9454.09	4.2973	1.31	6797.57	3.0898	0.94
2300	9883.82	4.2973	1.31	7351.60	3.1963	0.97
2400	10497.6	4.3740	1.33	7415.53	3.0898	0.94
2500	10743.2	4.2973	1.31	8257.24	3.3028	1.00
2600	11173.0	4.2973	1.31	8864.54	3.4094	1.03
2700	12273.9	4.5459	1.38	9493.16	3.5159	1.07
2800	12728.5	4.2973	1.31	9546.43	3.4094	1.03
2900	12927.7	4.2973	1.31	9887.3	3.4094	1.03
3000	12891.9	4.5459	1.38	10228.3	3.4094	1.03
3100	14092.3	4.5459	1.38	10889.6	3.5127	1.07

Table 3: B) Overburden Gradient in Well B-2 Using Density and Sonic Logs

Depth (m)	Sonic Log over-burden pressure (psi)	Sonic Log Overburden pressure gradient (psi/m)	Sonic Log Overburden pressure gradient (Psi/ft.)	Density Log over-burden pressure (psi)	Density Log Overburden pressure Gradient (psi/m)	Overburden pressure gradient (psi/ft)
2000	8452.57	4.226	1.28	5966.52	2.9832	0.90
2100	9024.36	4.2973	1.31	6936.07	3.3028	1.00
2200	9454.09	4.2973	1.31	7266.36	3.3028	1.00
2300	10060.26	4.3740	1.33	7841.7	3.4094	1.03
2400	10497.66	4.3740	1.33	8182.65	3.4094	1.03
2500	10935.06	4.3740	1.33	8789.96	3.5159	1.07
2600	11372.47	4.061	1.23	8864.54	3.4094	1.03
2700	11809.87	4.374	1.33	9205.48	3.4094	1.03
2800	12247.74	4.374	1.35	8651.45	3.0898	0.94
2900	12927.74	4.4578	1.35	9578.39	3.3028	1.00
3000	13373.52	4.4578	1.35	10228.3	3.4094	1.03
3100	13819.31	4.4578	1.35	10569.2	3.4094	1.03

Table 4: Pore Pressure Profiles for Wells B-1 and B-2

Depth (m)	Depth (ft.)	Poisson ratio (µ)	Effective stress gradient (σv) = 1-µ	Pore pressure gradient (B-1)	Pore pressure gradient (B-2)	Pore pressure (B-1)	Pore pressure (B-2)
2000	6561.6	0.466	0.524	0.446	0.376	2860.9	2401.5
2100	6889.7	0.467	0.533	0.497	0.467	3424.2	3217.48
2200	7217.76	0.468	0.532	0.41	0.468	2959.3	3379.91
2300	7545.84	0.470	0.53	0.44	0.5	3320.2	3772.92
2400	7873.92	0.472	0.528	0.412	0.502	3244.1	3952.90
2500	8202	0.473	0.527	0.473	0.543	3879.6	4453.68
2600	8530.08	0.475	0.525	0.505	0.505	4307.7	4307.69
2700	8858.16	0.476	0.524	0.546	0.506	4836.6	4482.23
2800	9186.24	0.477	0.523	0.507	0.381	4657.4	3499.95
2900	9514.32	0.478	0.522	0.508	0.478	4833.3	4547.84
3000	9842.4	0.479	0.521	0.509	0.509	5009.8	5009.78
3100	10170.5	0.481	0.519	0.551	0.511	5603.9	5197.11