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Overpressure Prediction In The North-West Niger Delta, Using Porosity Data

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Abstract: *Overpressure prediction in the North West of Niger Delta, using porosity data was carried out to safeguard hazards associated with drilling accident due to blowout. In the absence of seismic data to predict overpressure, porosity-dependent parameters and acoustic impedance could be used to predict the tops of overpressured zones in the area of study in the Niger Delta. Overpressure prediction is vital for safe and economic drilling. Composite logs were used to obtain the required data by digitizing the logs and deduction using the appropriate relationships. The findings from the study show that porosity decreases with depth, with overpressure zone detected at about 3500m depth due to porosity deviation from normal trend. Pressure gradient in the upper normal pressure of the field is determined to be 0.989 psi/ft, this implies that within the established normal pressure gradient of 0.71 - 1.1 psi/ft in the Niger Delta. Formation overpressure gradient is determined to be 1.40 psi/ft. The overpressure zone coincides within the high shale-to-sand ratio of Agbada under compacted Formation. The identification of the tops of overpressure zones in any formation penetrated by a borehole enhances the use of normal drilling techniques of the borehole. This also reduces the cost of drilling the entire well as the special drilling technique will be applied only in the overpressure zones. This finding can aid in the prevention of drilling accident and resource wastage in exploration activities.*
Key words: *Porosity, acoustic velocity, compaction, lithology, overpressure, sedimentary basin.*

I. Introduction

In petroleum exploration, the consequences of overpressures can be desirable in the sense that they encourage hydrocarbon migration. They can also reinforce the efficiency of the seal and thus protect the accumulation or can even have been at the origin of the structure through clay diapirism (Mouchet and Mitchell, 1989). Sometimes the impacts of overpressures are undesirable since they are often unpredictable and unquantifiable ahead of drilling. Exploration drilling may sustain heavy losses in both human and financial terms because of incomplete knowledge of formation pressure (Harkins and Baugher, 1969). Prediction of overpressure before drilling is critical at several stages in the exploration and development processes. In the exploration phase, it can assist in assessing the seal effectiveness and in mapping hydrocarbon migration pathways. It can also assist in the analysis of trap configurations and basin geometry, and provide calibration for basin modelling. In the drilling phase, an accurate pore-pressure prediction can be vital for safe and economic drilling (Dutta, 2002; Nfor, 2011).

Several authors have used different methods to determine overpressure zones in the Niger Delta. Owolabi *et al* (1990) used resistivity logs, Osinowo *et al* (2007) used interval transit time, Omolaiye *et al* (2009) used seismic data. Some of the other methods appplied include rate of penetration, (Jorden and Orval, 1964; Combs, 1968), temperature was also applied by Jones (1978), and shale density and velocity analysis by Satinder and Huffman (2006). This paper uses interval transit-time porosity and acoustic impedance to establish top of overpressure.

In the Niger Delta basin, where petroleum exploration has been continuing since the 1950s, it becomes necessary to assess overpressure zones in the basin, which is one of the hydraulic properties of rocks.

II. Causes and Effects of Overpressure

In the world's sedimentary basins, overpressures are associated with permeability barriers, tectonics, shale diagenesis, basin structure, and undercompaction among other factors (Hiller, 1991). In the Niger Delta basin, the very rapid deposition of Akata shales on the basement top has a sealing effect on the pores of shales. The sealing effect ceases the vertical flow of water and fluids cannot migrate freely. This causes undercompaction of the formations and abnormal high pressures are created (Bruce, 1973). The sealing effect can also be created as undercompacted and buoyant Akata shales below upheave into the overlying Agbada formation as demonstrated in Figure 3 (Weber and Daukuru, 1975; Whiteman, 1982).

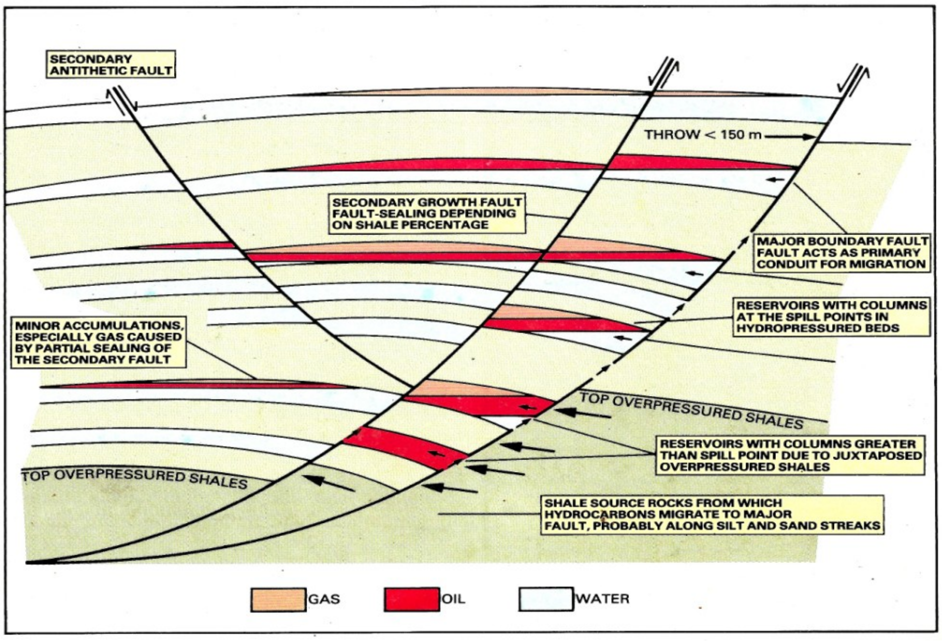

Fig. 3: Representation of overpressure communication in the Niger Delta by Weber and Daukuru, 1975, Whiteman, 1982.

GEOLOGY OF NIGER DELTA, NIGERIA

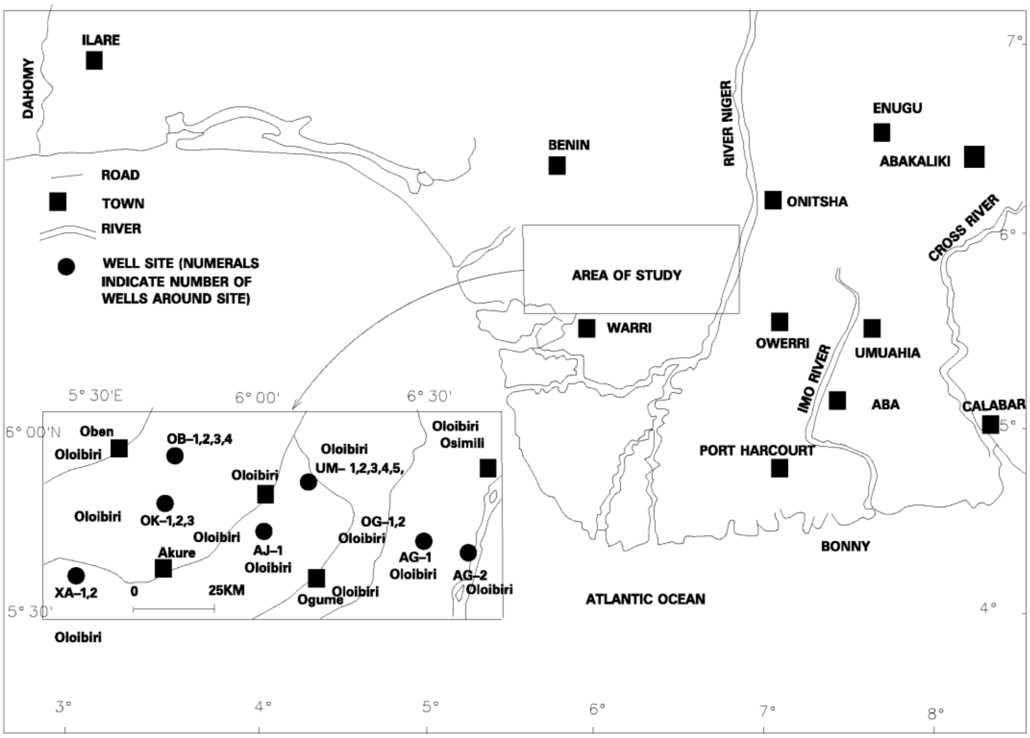

Fig. 1: Map of southern Nigeria showing the Niger delta region and the study area (Short and Stauble 1967)

The Niger Delta is situated at the West African margin of the Gulf of Guinea (Fig. 1). The stratigraphic sequence of the Niger Delta basin has been described by Short and Stauble (1967), Ofoegbu (1985), Uko *et al.* (1992). The Delta is composed of three major structural Formations: Akata, Agbada and Benin Formations (Fig. 2).

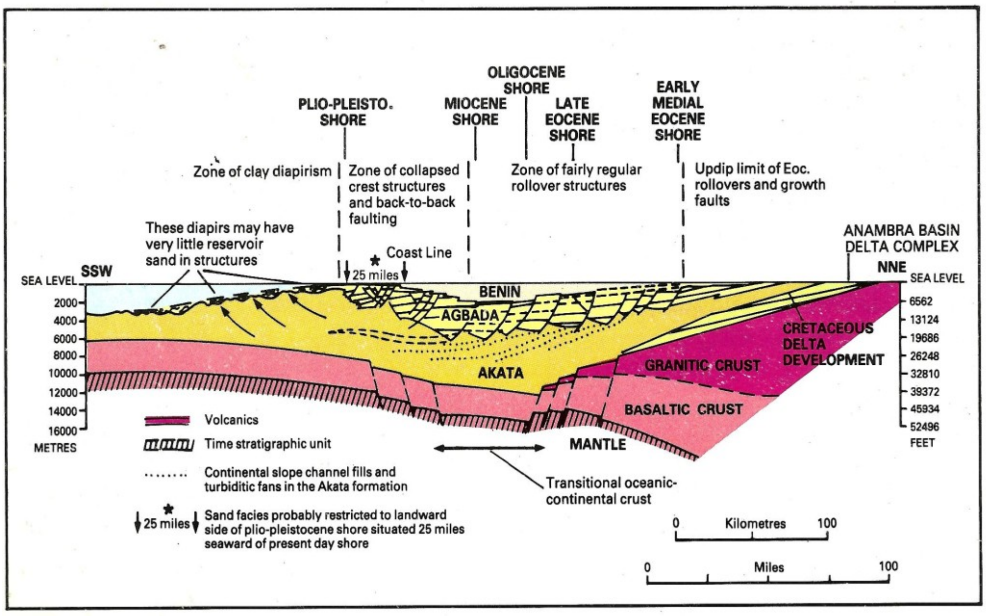

Fig. 2: Structural section of the Niger Delta Complex showing Benin, Agbada and Akata formations (Short and Stauble, 1967)

The Benin Formation is the upper alluvial coastal plain depositional environment of the Niger Delta Complex. It extends from the west Niger Delta across the entire Niger Delta area and to the south beyond the present coastline. The formation was deposited in a continental fluviatile environment and composed almost entirely of non-marine sandstone. It consists of coarse-grained sandstones, gravel lignite streaks and wood fragments with minor intercalation of shales. Benin Formation is of Miocene to younger age and has a variable thickness that exceeds 1820 m. In the subsurface, it is of Oligocene age in the north becoming progressively younger southwards but ranges from Miocene to Recent as generally accepted. Very little hydrocarbon accumulation has been associated with this formation (Short and Stauble, 1967).

The Agbada Formation underlies the Benin Formation. It was laid down in paralic brackish to marine fluviatile, coastal environments. It is made up mainly of alternating sandstone, silt and shale. The sandstones are poorly sorted, rounded to sub-rounded, slightly consolidated but majority are unconsolidated. The sandstones grade into shale in the lower part of the formation. Agbada Formation ranges in age from Eocene in the north to Pliocene in the south. The sandy parts of the formation are known to constitute the main hydrocarbon reservoirs of the delta oil fields and the shales constitute seals to the reservoirs. The thickness of the formation reaches a maximum of about 4500 m (Short and Stauble, 1967).

The Akata Formation is the lowest unit of the Niger Delta complex. It is composed of mainly shale with sandstones and siltstones locally interbedded. The Formation becomes shalier with depth. It was deposited in a marine environment and has a thickness, which may reach 7000 m in the central part of the delta. The Akata Formation outcrops offshore in diapirs along the continental slope, and onshore in the north east, where they are called Imo Shale. The age of the Akata Formation ranges from Eocene to Recent (Short and Stauble, 1967).

III. Materials And Methods

In this paper, critical investigation was carried out on 19 closely-spaced petroleum wells-logs. The data obtained from these wells were used to estimate parameters such as porosity, velocity, acoustic impedance, overburden pressure, and lithologies.

Lithology Estimation

Gamma-ray log (Fig. 4) was used to delineate the lithologies at the pre-determined depth intervals. The American Petroleum Institute (API) values ranges from sandstone line 0 to shale line 150. As the signature of the log move towards the higher values, the formation becomes more shaly. The delineation approach enabled us to estimate and establish the lithological sequence of the formation of the study area. Table 1 shows sand percentages at various depths, while Figure 5 is a cross plot of depth-sand percentages.

Porosity estimation

The Sonic logs, (Fig.4), were digitized to obtain transit time with which porosity is being computed using the relationship established by Schlumberger (1985):

$$\phi_{sonic} = 0.625\left(1 - \frac{\Delta t_{ma}}{\Delta t}\right) \quad (1)$$

where Δt_{ma} is the transit time of the matrix material (μs/ft), and Δt = reading on the Sonic log (μs/ft). The interval transit time values were picked from the sonic log with depth. The reciprocal of the transit time gives the transit velocity. Porosity is treated as a function of lithology and depth, ranging from 5% for shales at a depth of about 4250m and 51% for surface sandstones.

Acoustic velocity and impedance estimation

Acoustic velocity, Vp, was computed by taking the reciprocal of the transit time, and is given as:

$$V_P = \frac{1}{\Delta t} \quad (2)$$

Bulk density with depth was estimated using Density log. Compressional acoustic impedance, AI, is a product of bulk density and acoustic velocity, and is given as:

$$AI = V_p\rho \quad (3)$$

measured in $gcm^{-2}s^{-1}$, where V_p is velocity in cms^{-1}, and ρ is density in gcm^{-3}.

Pore overburden pressure

This parameter was deduced using the relation:

$$P = hg\rho \quad (4)$$

Where P = overburden pressure, h = depth of burial of rock, ρ = density of rock, g = acceleration due to gravity.

IV. Results and Discussion

Normal and abnormal pore pressure zones were delineated based on the principle of normal and deviation from normal porosity trends. The transition between the two trends signifies the top of the overpressure zone. The accuracy of the predicted overpressure zone was confirmed from the computed density-derived acoustic impedance for shale-sandstone lithologies, Figure 6. The variation to the depth of the overpressure between the predicted and the observed values was less than 5m, with confidence of over 90%. This depth conforms to the thick marine Agbada shales using composite log. Prediction of the top of the overpressure zone within the North-west of Niger Delta for potential wells will be total depth beyond 3300m sub-sea for safer drilling programme.

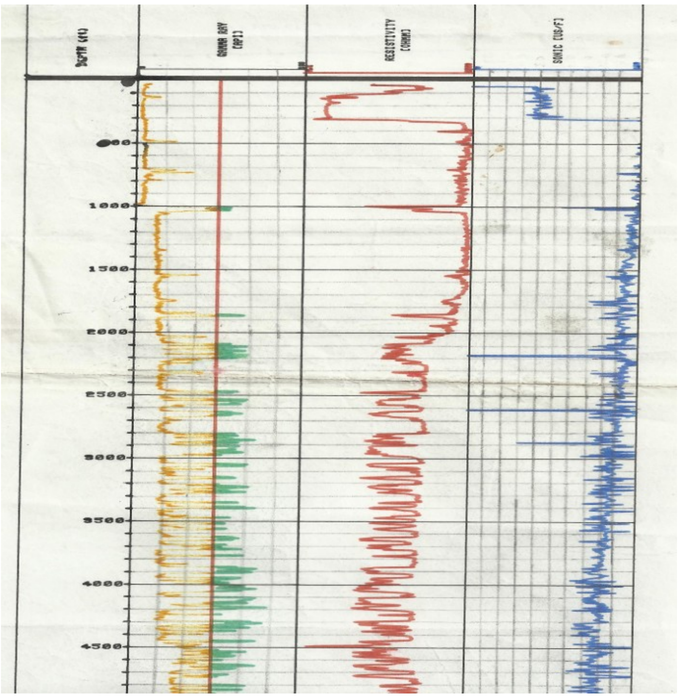

Fig. 4: Typical composite well Log for estimating sand ratio and transit travel time.

Depth (m)	Sand volume (%)	Velocity (Kms^{-1})	Porosity (%)	Density (gcm^{-3})	Pore overburden pressure (psi)	Acoustic impedance (g/cm.s)	Overburden pressure gradient (psi/ft)
1408	90	8.33	34	2.01	4103.616	1674330	0.94425
1415	90	8	35	2.05	4206.088	1640000	0.898189
1454	90	7.94	35	1.95	4111.185	1548300	0.902795
1484	90	9.52	29	1.96	4217.528	1865920	0.981099
1524	90	8.33	34	2.13	4706.874	1774290	0.898189
1609	90	8.33	34	1.95	4549.448	1624350	0.967281
1655	65	9.09	31	2.1	5039.475	1908900	0.948856
1695	80	9.52	29	2.06	5062.965	1961120	0.948856
1771	85	10	28	2.06	5289.977	2060000	0.898189
1865	85	9.52	29	1.95	5273.288	1856400	0.967281
1871	85	10	28	2.1	5697.195	2100000	0.967281
1978	85	9.09	31	2.1	6023.01	1908900	0.967281
2063	90	10	28	2.1	6281.835	2100000	0.985705
2100	80	10	28	2.14	6516.3	2140000	0.967281
2106	85	10	28	2.1	6412.77	2100000	0.967281
2195	85	10.53	26	2.1	6683.775	2211300	0.981099
2298	85	10.53	26	2.13	7097.373	2242890	1.013342
2341	85	10	28	2.2	7467.79	2200000	1.013342
2377	85	11.76	22	2.2	7582.63	2587200	1.013342
2429	85	10.53	26	2.2	7748.51	2316600	1.013342
2463	85	10.87	25	2.2	7856.97	2391400	0.94425
2499	90	11.11	24	2.05	7428.278	2277550	0.990311
2609	90	11.11	24	2.15	8133.558	2388650	0.94425
2643	65	11.76	22	2.05	7856.318	2410800	0.990311
2744	80	11.76	22	2.15	8554.42	2528400	1.02716
2886	65	11.76	22	2.23	9331.881	2622480	1.036372
2896	65	11.36	23	2.25	9448.2	2556000	1.013342
2972	75	11.9	21	2.2	9480.68	2618000	1.017948
3091	75	12.05	21	2.21	9905.11	2663050	1.031767
3141	80	12.5	19	2.24	10201.97	2800000	1.013342
3163	50	12.5	19	2.2	10089.97	2750000	1.02716
3222	60	12.82	18	2.23	10418.34	2858860	1.036372
3253	55	12.5	19	2.25	10612.91	2812500	0.94425
3301	65	12.5	19	2.05	9812.223	2562500	0.990311
3324	90	11.76	22	2.15	10362.57	2528400	0.92122
3383	95	9.52	29	2	9810.7	1904000	1.059403
3414	95	13.51	16	2.3	11385.69	3107300	1.036373
3447	95	13.7	15	2.25	11245.84	3082500	1.013342
3453	90	12.82	18	2.2	11015.07	2820400	1.036373
3475	90	12.82	18	2.25	11337.19	2884500	1.082434
3466	80	13.16	17	2.35	11810.4	3092600	1.036372
3505	80	13.16	17	2.25	11435.06	2961000	1.059403
3517	80	11.36	23	2.3	11729.2	2612800	1.059403
3566	80	13.7	15	2.3	11892.61	3151000	0.990312

3574	65	12.82	18	2.15	11141.95	2756300	1.036372
3597	65	13.7	15	2.25	11735.21	3082500	1.082433
3603	60	13.33	16	2.35	12277.22	3132550	1.082434
3634	50	11.11	24	2.35	12382.86	2610850	1.059403
3671	55	14.29	13	2.3	12242.79	3286700	1.082433
3695	65	13.7	15	2.35	12590.71	3219500	0.967281
3709	60	13.89	14	2.1	11293.91	2916900	1.059403
3749	75	11.11	24	2.3	12502.92	2555300	1.036372
3789	75	12.5	19	2.25	12361.61	2812500	1.082434
3810	75	10.53	26	2.35	12982.58	2474550	1.036373
3822	75	10	28	2.25	12469.28	2250000	1.082433
3848	75	11.11	24	2.35	13112.06	2610850	1.013342
3862	75	12.82	18	2.2	12319.78	2820400	1.105464
3871	80	10.31	27	2.4	13471.08	2474400	1.077827
3894	90	10.53	26	2.34	13212.34	2464020	1.082433
3904	50	10	28	2.35	13302.88	2350000	1.036373
3923	75	11.11	24	2.25	12798.79	2499750	1.036372
3928	75	10.53	26	2.25	12815.1	2369250	1.036372
3936	75	10.53	26	2.25	12841.2	2369250	1.036373
3951	75	12.5	19	2.25	12890.14	2812500	1.036373
3962	75	10.2	27	2.25	12926.03	2295000	1.059403
3984	85	10.31	27	2.3	13286.64	2371300	1.059403
4001	85	9.43	29	2.3	13343.34	2168900	1.082434
4022	85	9.52	29	2.35	13704.97	2237200	1.082434
4033	85	10	28	2.35	13742.45	2350000	1.082434

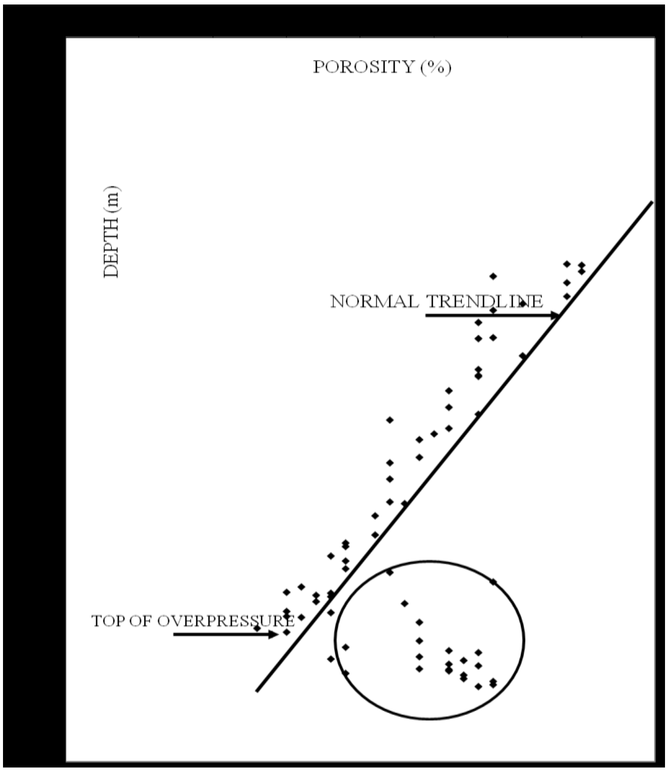

Fig. 5: Depth-porosity cross-plot

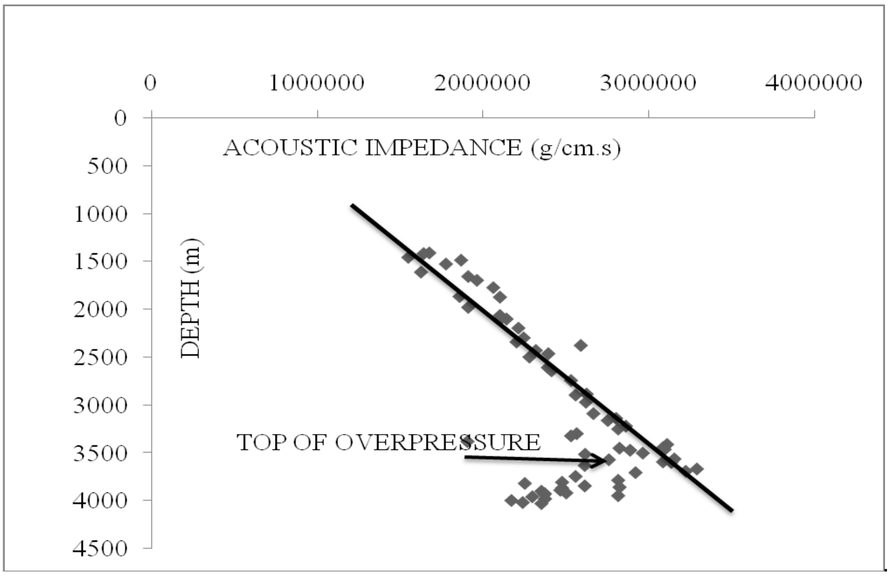

Fig. 6: Depth-Log Velocity cross-plot

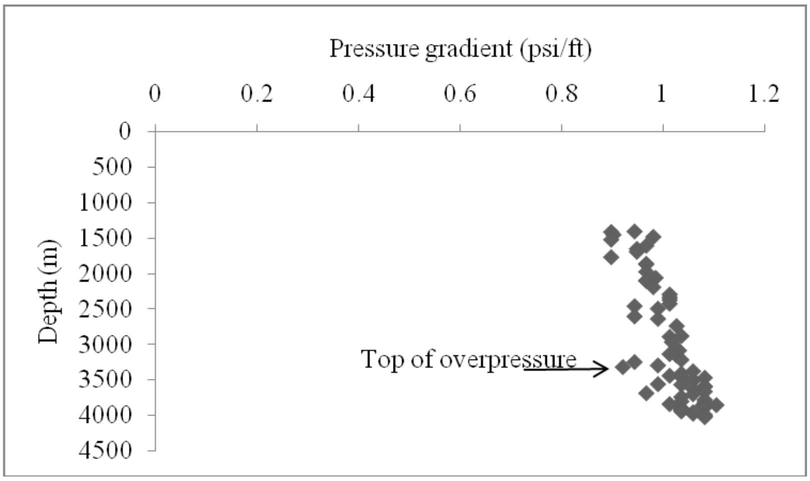

Fig. 7: Depth-Pore overburden pressure gradient- cross-plot

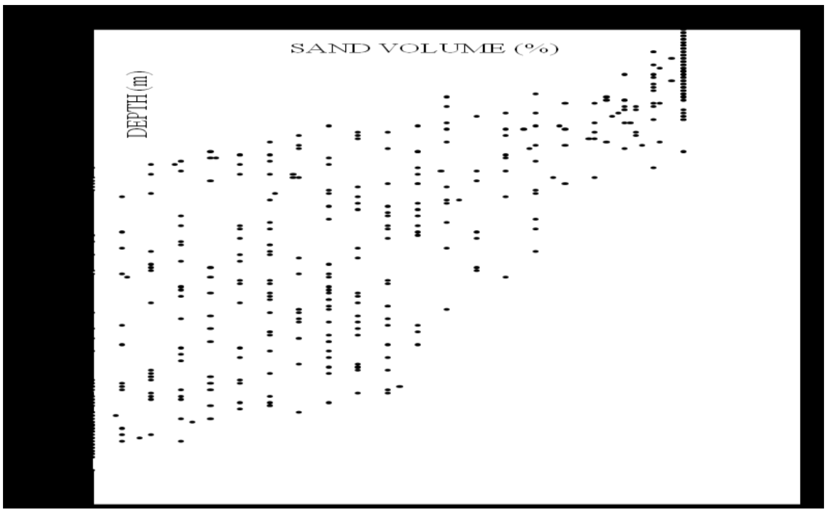

Fig 8 Depth-Sand volume cross plot

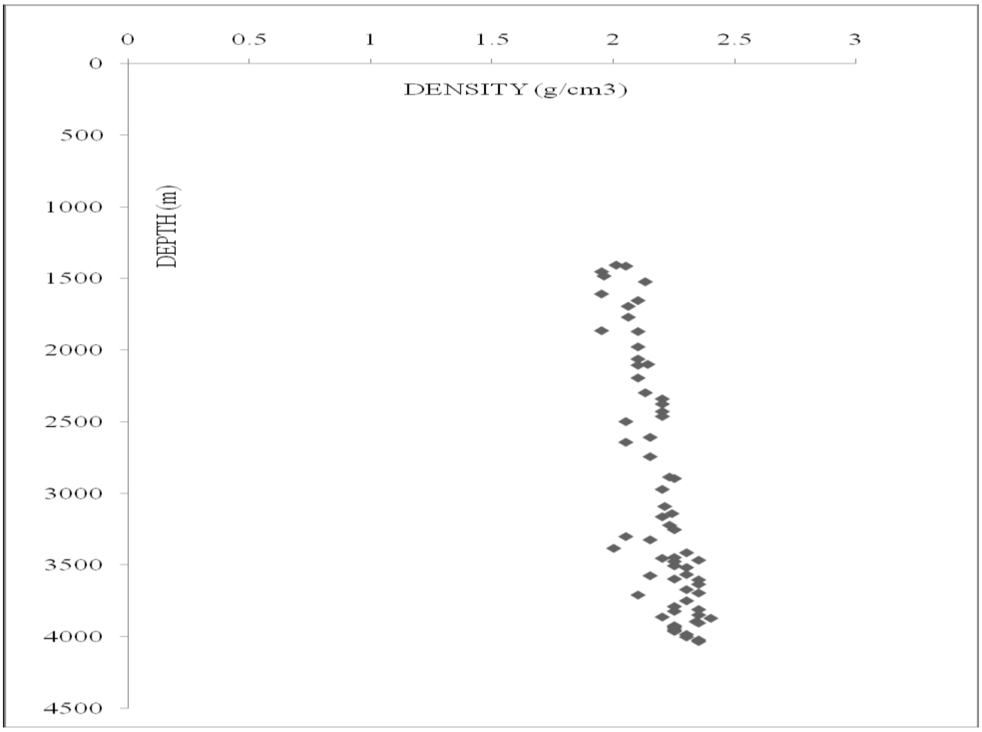

Fig. 9: Depth-density cross-plot

Porosity

Porosity values range between 9% at depth and 51% at the surface. The computed porosity is plotted against depth. Porosity decreases with depth.

The porosities were also plotted against depth on a semi log paper with porosity values on logarithmic scale and depth values on the linear scale. A line of best fit is drawn through the plotted points showing porosity-decrease-with-depth trend, in normal compaction (Fig. 5).

Pressure gradient

In normal pressure environments the plots of depth versus porosity on semi log paper show all data points falling along the line of normal compaction trend (Figures 5 - 7). This plot establishes both normal and abnormal compaction trend with the view to predict well abnormal geopressures. A sudden increase in porosity with depth implies the presence of overpressures (under compaction), Figures 5, 6 and 7 is due to an increase in porosity, implying the presence of overpressures (under compaction). Under normal compaction, porosity of rocks decrease with depth, but when overpressured (under compacted) layers are encountered, the trend is reversed in Figures 5, 6 and 7. Abnormal formation pressures at a depth of between 3300 and 4000m was observed in the area of study.

V. Conclusion

In conclusion, Porosity is controlled by depth of burial; Porosity increases below the top of undercompacted overpressured shaley Agbada formation at the depth of 3300m; Over pressure is encountered from about 3300m which is an effective depth of concern as effective pressure at this depth is enormous to cause massive devastation if not accurately predicted drilling. Pressure gradient in the upper normal pressure of the field is determined to be 0.989 psi/ft, this implies that within the established normal pressure gradient of 0.71 - 1.1 psi/ft in the Niger Delta. Formation overpressure gradient is determined to be 1.40 psi/ft. The overpressure zone coincides within the high shale-to-sand ratio of Agbada under compacted Formation. The identification of the tops of overpressure zones in any formation penetrated by a borehole enhances the use of normal drilling techniques of the borehole. This also reduces the cost of drilling the entire well as the special drilling technique will be applied only in the overpressure zones. This finding can aid in the prevention of drilling accident and resource wastage in exploration activities.

Acknowledgements

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