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WIRELINE, MWD AND MUD LOGS: A THREE- WAY COMPLIMENTARY APPROACH TO REDUCE UNCERTAINTIES IN PORE PRESSURE ANALYSIS IN THE *SMK* FIELD, ONSHORE NIGER DELTA

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Abstract

Accurate pore pressure evaluation is essential for safe and cost-effective well drilling and also provides quality geo-scientific databases for future drilling prospects. The study carried out on an onshore Niger Delta field, dealt with the concept of overpressure, its mechanism and estimation using real-time mud log data/MWD logs and post drill wireline logs and comparing the results quantitatively to build a more robust geopressure model for the field using all data sets.

Quantitative pressure analysis carried out on eight wells using Wireline/MWD logs revealed that compaction disequilibrium is the dominant geopressure mechanism in the field with trend deviations from normal compaction clearly discernible from the sonic logs around 9000ft. Shale pressures determined using standard Eaton and Equivalent depth methods revealed three pressure regimes, the normally pressured section(≤ 0.442 psi/ft), the transition zone(0.442 – 0.495psi/ft) and the abnormally pressured section(≥ 0.495 to 0.70 psi/ft) showing SMK 1,8,11,12 and 13 to be moderately geo-pressured which agrees with a disequilibrium compaction model while SMK 6,10 and 14 are normally pressured to transitionally pressured wells with resistivity logs spiking shale pressures in the MWD logs.

The pore pressure estimation using the D-Exponent served as both as a quantifier by identifying the over-pressured wells (SMKs 1, 12 and 13) and the normally/transitionally pressured wells (SMKs 6 and 14) and as a calibrator to confirm the accuracy and precision of pore pressure prediction using the well logs and a careful analysis showed that these results are corroborated excellently by quantitative pressure analysis from the five mud logs using the D-exponent.

Keywords: Wireline/MWD log, Pore pressure, Mud Log, Mechanism, D-Exponent, Niger Delta.

1. Introduction

Pore pressure analysis is vital to the exploration efforts of any upstream industry whose goal is to identify, quantify and develop fields containing a commercial accumulation of hydrocarbons. Not only is it useful in well site delineation but also in ensuring safe and cost effective drilling operations as well as to minimize any potential environmental degradation from oil spillage resulting from drilling operations. Due to the inhomogeneities in pressure distributions in basins across the world, various ways of recognising pressure regimes have evolved to reduce uncertainties in pore pressure analysis in terms of mechanisms (unloading or loading) and quantification (effective stress methods and Bower's unloading technique) which in turn help to develop a robust geopressure model on both local and regional scales.

The Tertiary Niger Delta basin is a young, rapidly filling a sedimentary basin (Figure 1) with fast burial and sedimentation rates where disruption in the balance between sedimentation rate and pore fluid expulsion leads to under-compaction. Upon further burial, these zones become closed off, and consequently, dewatering is halted leading to over-pressuring of such enclosed zones. Two broad mechanisms for over-pressuring have so far been identified namely Loading and Unloading mechanisms. Loading mechanisms include disequilibrium compaction and tectonic compression. Unloading mechanisms include clay diagenetic processes such as smectite-illite transformation [1], hydrocarbon generation [2], and lateral or vertical transfers [3-5].

Pore pressures can be highly inhomogenous even down to the reservoir level, and various basins around the world have been known to exhibit more than one type of mechanism of overpressure generation. Examples include the Malay basin, Kutai basin [6] and recently in the Niger Delta [7-8] where deep seated onshore reservoirs and offshore (shelf) reservoirs exhibit-ted very different pressure regimes which necessitated a different method of quantification compared to shallower reservoirs (Figure 1).

This study aims at incorporating both real times (Mud and MWD – Measurement While Drilling-logs) and post drill(Wireline logs) to estimate pore pressures, compare and contrast effectiveness of prediction models to reduce uncertainties, narrow down the window of error and build confidence in both frontier, maturing and matured basins(Figure 2).

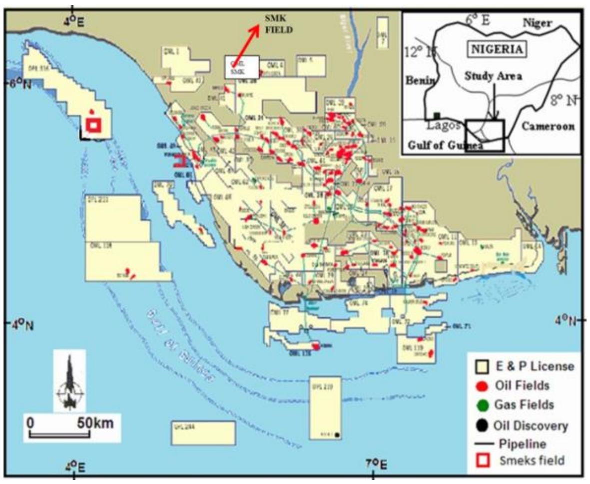

Figure 1. Concession map of the Niger Delta showing the SMK Field, (inset is the map of Nigeria) *(Modified after [?] Doust and Omatsola, 1990)*

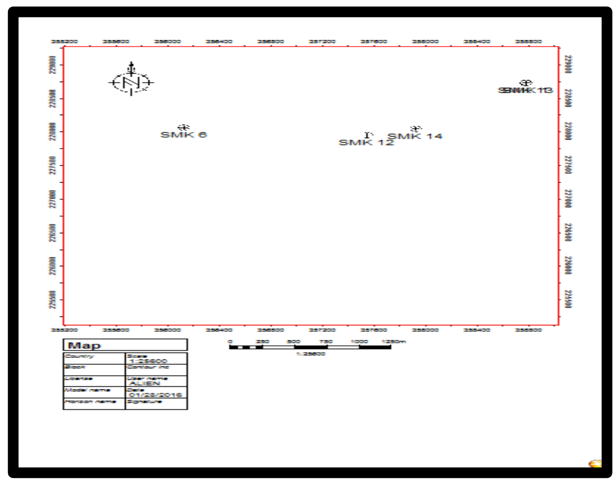

Figure 2. Base Map of the SMK Field

1.1. Geologic Setting

SMK field is located onshore in the Northern Delta depobelt, West of the Niger Delta between Latitudes 5°N and 6°N and Longitudes 5°E and 6°E and exhibit the typical characteristics associated with the regional structural settings of the Niger Delta, a delta situated in Southern Nigeria at the apex of the Gulf of Guinea on the West coast of Africa between latitudes 4^0 N and 6^0 N and longitude 3^0 E and 9^0 E [9]. It is one of the most prolific deltaic hydrocarbon provinces of the world (Figure 1). From the Eocene to the present, the Delta has prograded Southwestward, forming depobelts that represent the most active portion of the delta at each stage of its development [10]. The Niger Delta Province contains only one identified petroleum system [11-12]. Stratigraphically, there are three major for-mations corresponding to tripartite sequences from the oldest to youngest observed in the Niger Delta namely the Akata (marine shales ranging from 600 to 7000m, potential source rocks, Paleocene to recent in age), Agbada (paralic sequence of alternating sandstone, siltstone and clays, about 300 to 3500m, potential reservoir rocks, Eocene to recent in age) and Benin (continental sands, about 2000m thick, Eocene to recent in age)

2. Materials and methods

The data set was obtained from PanOcean Nigeria Limited through the Department of Petroleum Resources (DPR), Lagos state; Nigeria. The data was quality-checked for spiking, patching and corrected to true vertical depths, imported into RokDoc, Origin and Microsoft Excel software. The materials (data sets) used for this study include well logs (both Wireline and MWD), Mud logs and in some cases Well reports. Eight wells (6 wireline and 2 MWD logs), five mud logs, two well reports conclude the study database. The well logs were analysed for pore pressure (quantitative) using the RokDoc software with the five Mud logs pore pressure analysis (quantitative) done using Origin software. For the well logs (Wireline/MWD), the data include gamma ray (GR), sonic (SON) density (DENS), resistivity (LLD) and neutron (NEU) logs. The Gamma ray log was used to differentiate sand and shale units (lithology) and for well correlation to determine reservoir extent using cutoffs. Pore pressure estimation method (Eaton, Effective Stress, Dxc and Bowers) is largely dependent on the type of mechanism (loading or unloading) causing the overpressuring of sediments. For this study, Hoesni [13] method was utilized by plotting sonic velocities against bulk density for the wells and identifying mechanism based on which area of the plot the points fall (Figure 3).

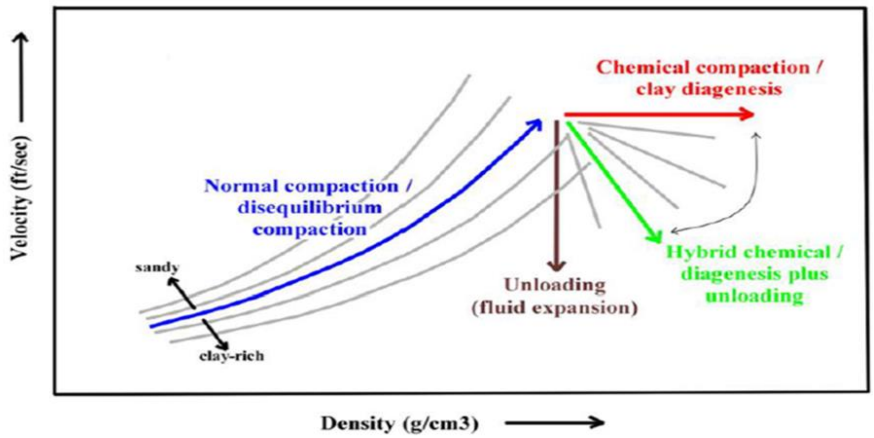

Figure 3. A schematic diagram of a velocity-density crossplot showing the possible components of overpressure generation mechanisms [13]

After determining mechanism, the next phase is determining the NCT (Normal Compaction Trend) which gives the ideal porosity loss with depth trend. The NCTs were derived by fitting the data to hydrostatically pressured intervals from around 300ft to about 9000ft with departures from this trend below 9000ft interpreted to be transitioned and geopressured zones. An exponential decay + matrix transit time equation called 3P-NCT for sonic, resistivity and density logs were used as shown in Equation 1, 2, [14],3 [15] and 4.

$\Delta t_n = (\Delta t_0 - \Delta t_m)e^{-bz} + \Delta t_m$ for the sonic log (1)

$\frac{1}{R_n} = \frac{(R_m - R_0)}{R0Rm^{(e-bz)}} + \frac{1}{Rm}$ for the resistivity log (2)

$\Phi = \Phi_0 e^{-bz}$ for the density log (3)

Prior to constructing the NCT from the density log, the density log values are usually converted to the porosity with the equation

$$\Phi_d = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_{fl}} \quad (4)$$

where: Δt_m = matrix transit time; Δt_n = transit time at NCT; b = empirical constant obtained by fitting transit time against depth z; R_n = NCT resistivity; R_m = matrix resistivity; R_0 = surface resistivity; ρ_{ma} = matrix density; ρ_b = density log represents bulk density of the formation; ρ_{fl} = density of the fluid in the formation; Φ is porosity at any given depth; Φ_0 is surface porosity; and e is the Naperian logarithm base.

For the mud logs, the NCT was extrapolated by picking clean, non- pyritic clays, plotting their D - exponent values on a semi-log grid, picking a line of best fit and extrapolating the trend to the required depth (Figure 8). All data plotting right of the line are deemed normally pressured while any deviation to the left of this line signify increasing underbalanced conditions or an overpressured zone is near.

The Overburden Trend is derived from the overburden/lithostatic model (the weight of overlying sediments and contained fluids with depth and calculated from the density log) [16] The density derived overburden model is converted from g/cm^3 to psi (pressure) using Equation 5

$$\sigma_{ob} = 0.433 * \rho_b * D \qquad (5)$$

where σob=overburden pressure; ρ_b =bulk density of sediment in grams/cubic meter; D= depth in ft; ρ_b, calculated from density logs and the overburden gradient is given by Equation 6

$$\frac{\sigma ob}{D} \text{ (psi/ft)} \qquad (6)$$

and Phydro (normal hydrostatic trend assumed from literature as 0.433psi/ft – [6].

The deep resistivity(LLD), sonic (SON) and density (DENS), logs were used in pore pressure identification (qualitative) and estimation (quantitative) using both Eaton and Equivalent depth methods respectively while the mud logs used the corrected ‘d’ exponent – Dxc [17] as shown in Equations 7, 8, 9 and 10.The quantified pore pressures were then presented as shale pressure profiles for well logs after which these results were compared with mud logs shale pressure profiles to reduce uncertainties and boost confidence in well drilling and completion operations.

Eaton’s method [18]

$$\text{Formation Pressure} = \left(S - (S - Pn)\left(\frac{\partial NCTsonic}{\partial To}\right)^{3.0}\right) \text{ for the sonic log} \qquad (7)$$

$$\text{Formation Pressure} = \left(S - (S - Pn)\left(\frac{R_o}{R_n}\right)^{1.2}\right) \text{ for the resistivity log} \qquad (8)$$

$$P = \left(S - (S - Pn)\left(\frac{D_{xco}}{D_{xcn}}\right)^{1.2}\right) \text{ for the corrected ‘d’ exponent} \qquad (9)$$

where S = overburden gradient in psi/ft; Pn = normal pore pressure gradient in psi/ft; ∂Tn = normal sonic trend from NCT; ∂To = observed sonic value; Pn = normal pore pressure gradient in psi/ft; Ro = observed resistivity; Rn = normal resistivity; where Dxco=observed Dxc, Dxcn = normal Dxc.

Equivalent Depth/Vertical/Effective stress method for Resistivity, sonic and density logs utilized Equation 10 in quantifying pore pressures.

$$P_a = \sigma_{v_A} - (\sigma_{v_B} - P_b) \qquad (10)$$

where P = pore pressure (psi) at point A; σ_{v_A}=vertical stress at A (psi/ft) ; σ_{v_B} =vertical stress at B (psi/ft) ; A = depth of interest in overpressure zone (ft) ; B = equivalent depth in normal pressure zone from A (ft).

3. Results and discussion

3.1. Mechanism

A sonic velocity versus density cross plot was used to analyse the geo/overpressure generating mechanism for the entire field using SMK 10, 12, 11 and 13 (Figure 4). The normal compaction/disequilibrium compaction sandy and shaly lines are the Gardner sandstone and shale lines. The data inside or located on the NCT (Normal Compaction Trend) are said to be normally compacted including those points for shales that are overpressured as a result of disequilibrium compaction while, if the data points fall outside the NCT, then the mechanism is unloading. A summary of data points and the equivalent overpressure generating mechanism is shown below (Figure 4). Thus, from the multi-well cross plot, the dominant mechanism for overpressure in the basin is disequilibrium compaction with a slightly rich clay subset and no conclusive evidence of secondary mechanisms observed in the field. Thus, standard shale based techniques such as Eaton, Equivalent Depth (Wireline/MWD logs) and D-exponent (Mud logs) can be used for overpressure quantification.

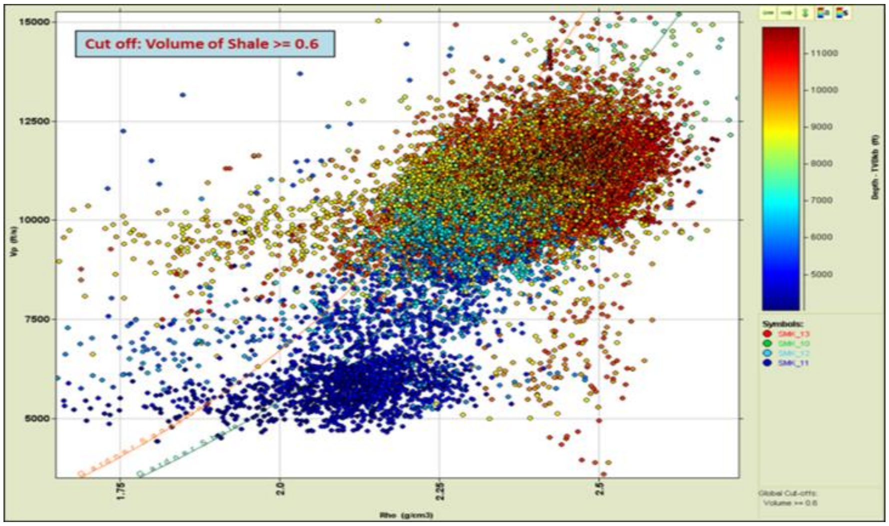

Figure 4. A multi-well velocity vs. density crossplot for wells showing dominant overpressure mechanism as disequilibrium compaction

3.2. Overburden and normal compaction trends

For this research, accurate bulk density values are determined from density logs and from all lithologies with the bulk density values plotted together on a single density versus depth plot in TVD (True Vertical Depth). (Figure 5). The bulk density values are converted to overburden pressure values used in the shale pressure calculations. An overburden gradient of 0.88psi/ft was derived for the SMK field which is slightly lower compared with the Gulf of Mexico maximum standard of 1psi/ft.

Well log Normal compaction trend (NCT) technique utilized the sonic derived NCT (preferred because it is relatively not affected by changes in hole size, formation temperature, and formation water salinity [16]) for this study with other log derived NCTs applied where sonic logs (SMK 14) are unavailable. Figure 6 shows the multi-well (SMK 11, 13, 8, 10, 12 and 1) Normal Compaction Trend for the field with trend deviation noticed around 9000ft as the start of a transition/overpressure zone.

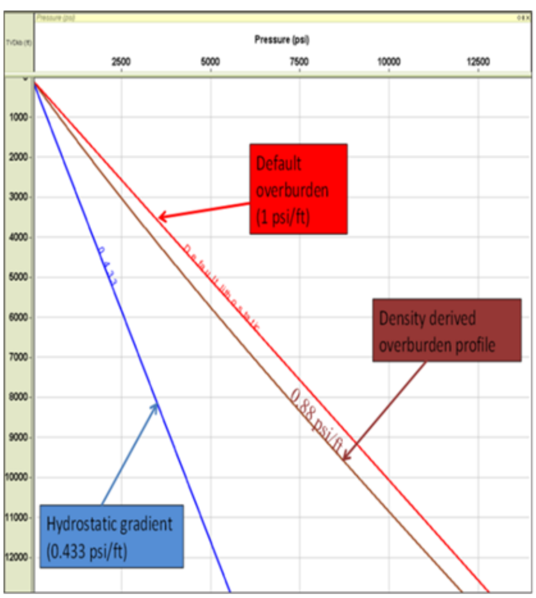

Figure 5. Field derived overburden profile from density logs(0.88psi/ft)

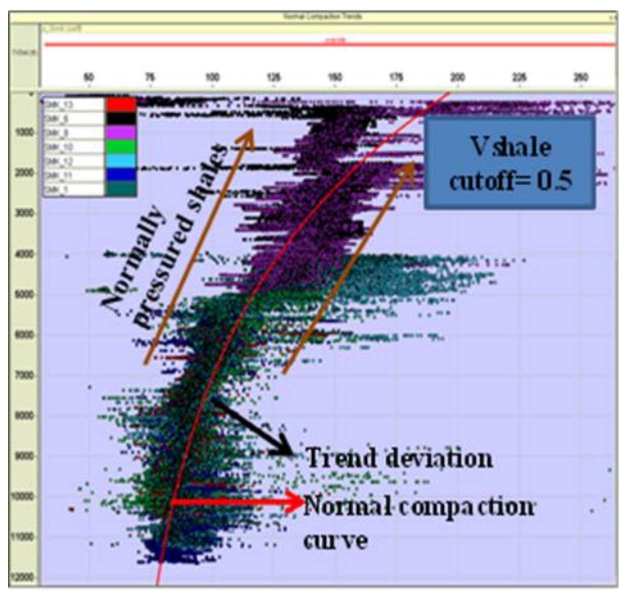

Figure 6. Sonic based shale–derived normal compaction trend (Data coloured by well type)

Figure 7 shows the Mud log NCT with trend deviation (left of trend line) noticed around 9000ft as the start of a transition/overpressure zone.

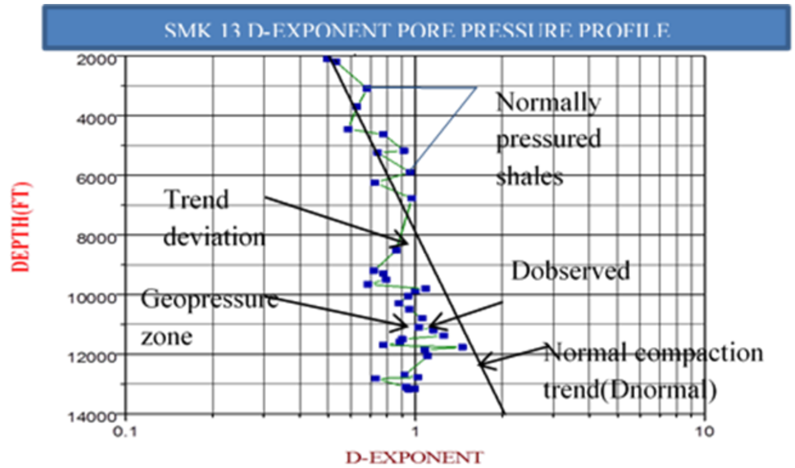

Figure 7. SMK 13 MUD log normal compaction

3.3. Overpressure evaluation

Conventional techniques such as Eaton and Equivalent depths were applied to quantify any overpressure encountered during analysis for the wireline and MWD logs since the prevailing overpressure generating mechanism is disequilibrium compaction (Figure 4) For the wells with mud logs (SMK 6, 12, 13 and 14), the corrected drilling exponent (Dxc) was used to quantify any existing overpressure encountered during analysis with well reports serving to supplement available data.

3.3.1. Overpressured wells

These are wells with encountered pore pressures well in excess of the normal or hydrostatic pressure of about 8.5ppg (pounds per gallon) i.e., ≤ 0.442psi/ft for the Niger Delta. A characteristic departure from the normal hydrostatic is noticed for the wells followed by a well-defined transition zone (0.442 – 0.495psi/ft) and the over-pressured section (≥ 0.495 psi/ft) encountered till the final drilled depth for all the wells. The wells involved include SMK 1, 8, 11, 12 and 13 with only SMKs 1, 12 and 13 having mud logs serving as both quantifiers and calibrators.(Figure 8b,12b and 13b) The trend deviation from the hydrostatic (clearly seen as bold blue, red and orange lines for well logs and red lines for the mud logs) outline shale pressure profiles showing sublithostatic parallel with the overburden revealing that overpressure results from disequilibrium compaction.(Figure 8a and 8b) Three pressure regimes were identified in all the wells (normal, transition and overpressure zones) with well log shale pressures '*tramlining'* one another showing the relatively similarity in response while mud shale pressure (estimated using the D-exponent) profile show characteristic pressure ramps (pore pressure buildups with depth) showing a distinct similarity in pore pressure estimation using both methods (Figures 8 to 12). Casing depth selection and kick zones were also used as calibrators (Figures 12a and 12b).

3.3.2. Normally/transitionally pressured wells

These are wells with encountered pore pressures either at normal/hydrostatic (≤ 0.442psi/ft – 8.5ppg (pounds per gallon) or in the transition zone (0.442 – 0.495psi/ft: 8.5 – 9.5ppg (pounds per gallon) or both with no appreciably higher pore pressures encountered till the final drilled depth for all the wells under consideration. (Figures 13 to 15). The wells involved include SMK 6 (Figure 13a), 10(Figure 14) and 14(Figures 15a) with only SMK 6 and 14 having mud logs serving as both quantifiers and calibrators (Figures 13b and 15b). The wells in this group are more or less similar in both pore pressure magnitude and direction

(Figure 14). For the wells with available composite mud logs (SMK 6 and 14), highly credible matches exist between the mud log and the wireline/MWD shale pressure profiles providing the best possible validity and effectiveness of both the mechanism of overpressuring as well as the method employed in overpressure estimation with the available data(Tables 2 and 8).

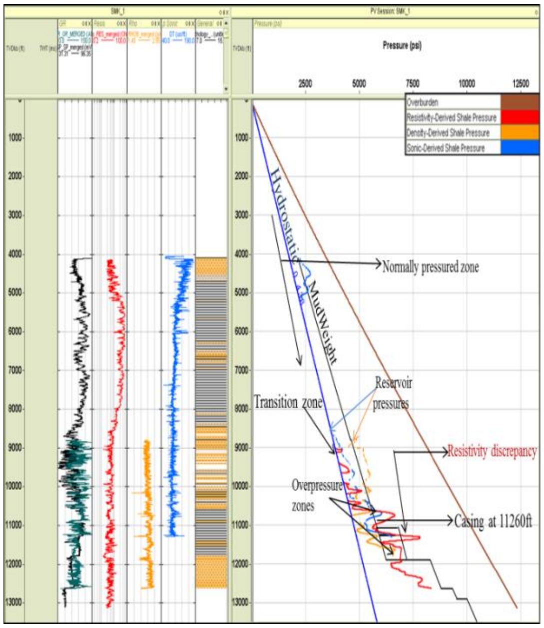

Figure 8a. SMK 1 pore pressure profile showing normal,transition and abnorma pressure zones

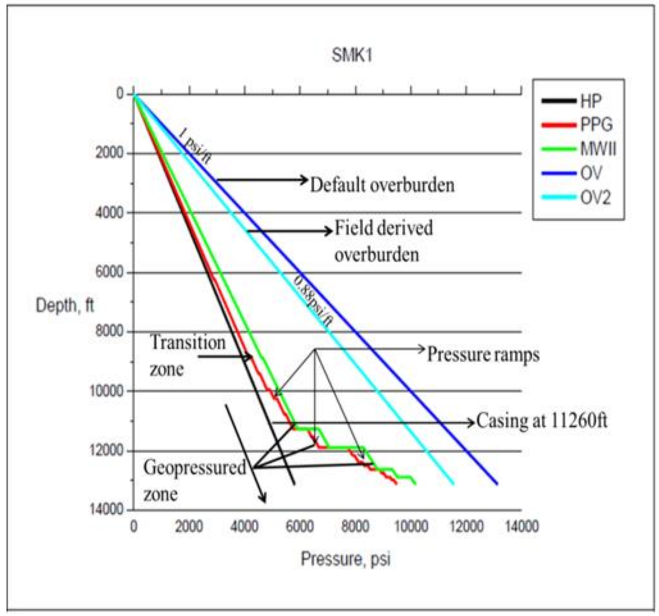

Figure 8b. SMK 1 Dxc profile where HP,PPG,MWII and OV are hydrostatic pressure, pore pressure, mud weight and overburden gradients

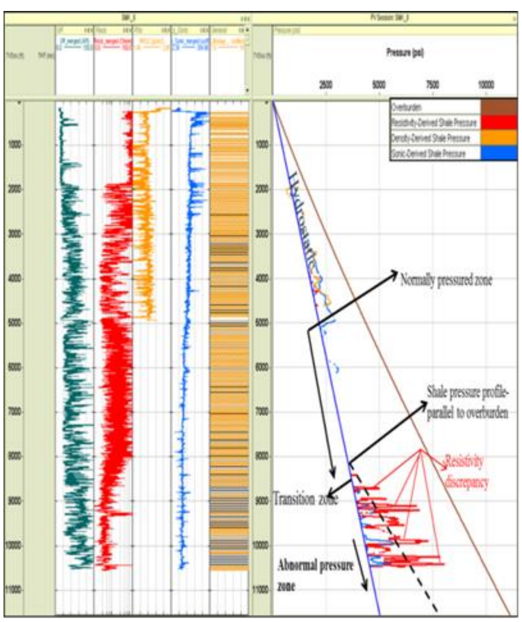

Figure 9. SMK 8 pore pressure profile showing normal, transition and abnormal pressure zones

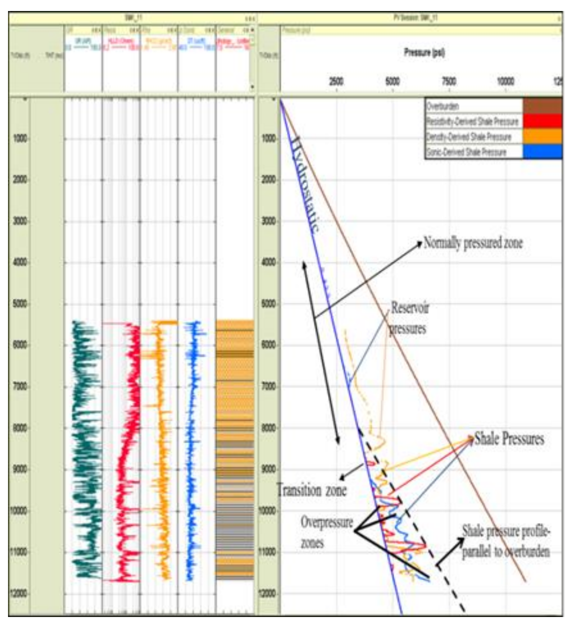

Figure 10. SMK 11 pressure view showing normal, transition and abnormal pressure zones

3.3.3. Comparison of results from well LOG and mud LOG shale pressure profiles

One of the study aims is to compare and contrast pressure profiles/magnitudes from the three-way approach (Wireline/MWD/Mud) with a view to determining the effectiveness and accuracy/precision of prediction to narrow down the window of error as well to build confidence in a maturing province like the Niger Delta. From the pore pressure profiles, pressure magnitudes using a particular approach/method were calculated at 1000ft intervals starting from points were trend departure from the normal hydrostatic gradient line was first observed (around 9000ft) for each SMK well in psi(pounds per square inch), psi/ft (pressure gradient) and ppg (pounds per gallon – the industry standard for pore pressure values using a universal conversion factor of 0.052) and compared with other methods as shown in Tables 1 to 9.

Table 1. SMK 1 Pressure magnitude comparison results

Depth (FT)	Pressure (psi)		Pressure gradient (psi/ft)		Magnitude (ppg) $\left(\frac{psi/ft}{0.052}\right)$	
	Well	Mud	Well	Mud	Well log	Mud log
9 000	4150(SON)	4200	0.46	0.47	8.8	9.0
10 000	4800(SON)	4800	0.48	0.48	9.2	9.2
11 000	5400(SON)	5400	0.49	0.49	9.4	9.4
12 000	7000(RES)	8000	0.58	0.67	11.2	12.9

Table 2. SMK 6 Pressure magnitude comparison analysis

Depth (Ft)	Pressure (psi)		Pressure/depth (psi/ft)		Magnitude (ppg) $\left(\frac{psi/ft}{0.052}\right)$	
	Well	Mud	Well	Mud	Well log	Mud log
10 000	4 800	4 500	0.48	0.45	9.2	8.7

Table 3. SMK 8 Pressure magnitude comparison results

Depth (Ft)	Pressure (psi)		Pressure/depth (psi/ft)		Magnitude (ppg) $\left(\frac{psi/ft}{0.052}\right)$	
	SON	RES	SON	RES	SON	RES
9 000	4 600	7 000	0.51	0.78	9.8	15.0
10 000	5 500	7 400	0 55	0 74	10.6	14.0

Table 4. SMK 10 Pressure magnitude comparison results

Depth (Ft)	Pressure (psi)		Pressure/depth (psi/ft)		Magnitude (ppg) $\left(\frac{psi/ft}{0.052}\right)$	
	SON	DENS	SON	DENS	SON	DENS
9 000	4 100	4 600	0.45	0.51	8.7	9.8
10 000	4 700	5 000	0 47	0 50	9.0	9.6

Table 5. SMK 11 Pressure magnitude comparison results

Depth (Ft)	Pressure (psi)		Pressure/depth (psi/ft)		Magnitude (ppg) $\left(\frac{psi/ft}{0.052}\right)$	
	SON	RENS	SON	RENS	SON	RENS
10 000	5 050	5 100	0.51	0.51	10.6	14.0
11 000	5 200	5 200	0 47	0 47	9.3	9.3

Table 6. SMK 12 Pressure magnitude comparison results

Depth (FT)	Pressure (psi)		Pressure gradient (psi/ft)		Magnitude (ppg) $\left(\frac{psi/ft}{0.052}\right)$	
	Well (SON)	Mud	Well	Mud	Well log	Mud log
9 000	3 750	4 000	0.42	0.44	8.1	8.5
10 000	4 500	4 500	0.45	0.45	8.7	8.7
11 000	5 100	5 050	0.46	0.46	8.8	8.8
12 000	NIL	7 700	NIL	0.64	NIL	12.3

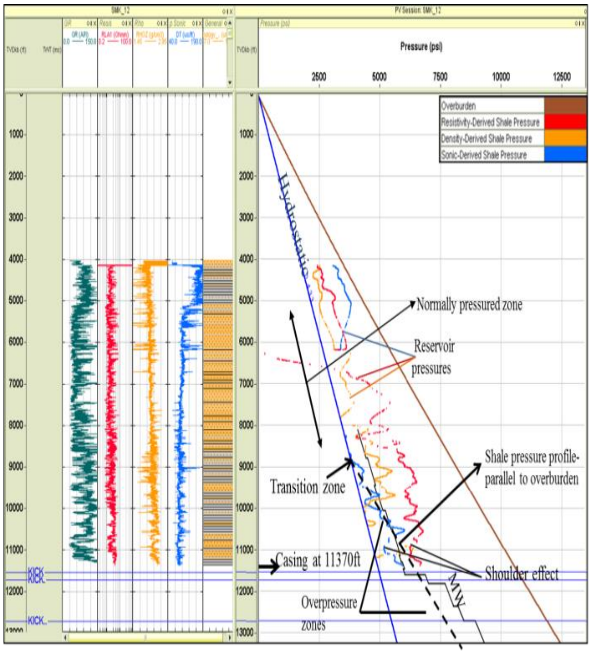

Figure 11a. SMK 12 pore pressure profile showing normal, transition and overpressure zones

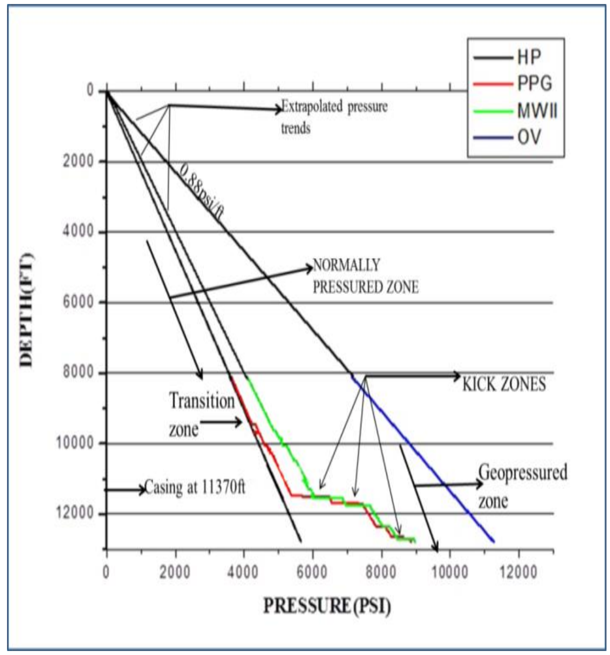

Figure 11b. SMK 12 Mud Dxc profile, HP, PPG, MWII hydrostatic pressure, pore pressure, mud weight and overburden pressure gradient resp.

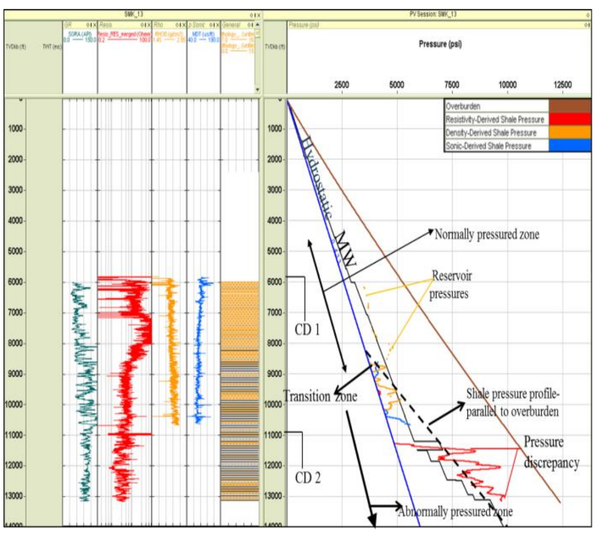

Figure 12a. SMK 13 pore pressure profile showing normal, transition and overpressure zones

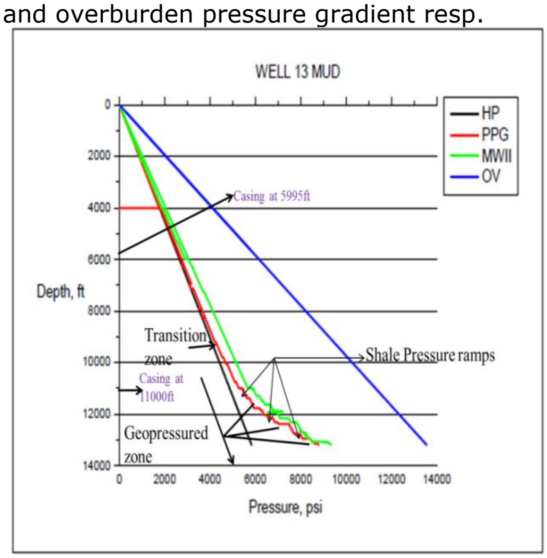

Figure 12b. SMK 13 Mud Dxc profile CD equals casing depth HP, PPG, MWII, OV are hydrostatic pressure, pore pressure mud weight and over-burden pressure gradient

Table 7. SMK 13 Pressure magnitude comparison results

Depth (FT)	Pressure (Psi)		Pressure gradient (psi/ft)		Magnitude (ppg)$\left(\frac{\text{psi/ft}}{0.052}\right)$	
	Well (SON)	Mud	Well	Mud	Well log	Mud log
9 000	4 100(SON)	4 000	0.46	0.44	8.8	8.5
10 000	4 800(RES)	4 800	0.48	0.48	9.2	9.2
11 000	NIL	5 200	NIL	0.47	NIL	9.0
12 000	9 800(RES)	6 500	0.81	0.54	15.6	10.4
13 000	9 900(RES)	8 800	8.76	0.68	14.6	13.1

RES - MWD; SON-wireline

Table 8. SMK 14 (MWD) Pressure magnitude comparison results

Depth (FT)	Pressure (Psi)		Pressure gradient (psi/ft)		Magnitude (ppg) $\left(\frac{\text{psi/ft}}{0.052}\right)$	
	Well (RES)	Mud	Well	Mud	Well log	Mud log
9 000	4 350	4 300	0.48	0.48	9.2	9.2
10 000	5 300	4 700	0.53	0.47	10.2	9.0
11 000	7 000	5 200	0.64	0.47	12.3	9.0

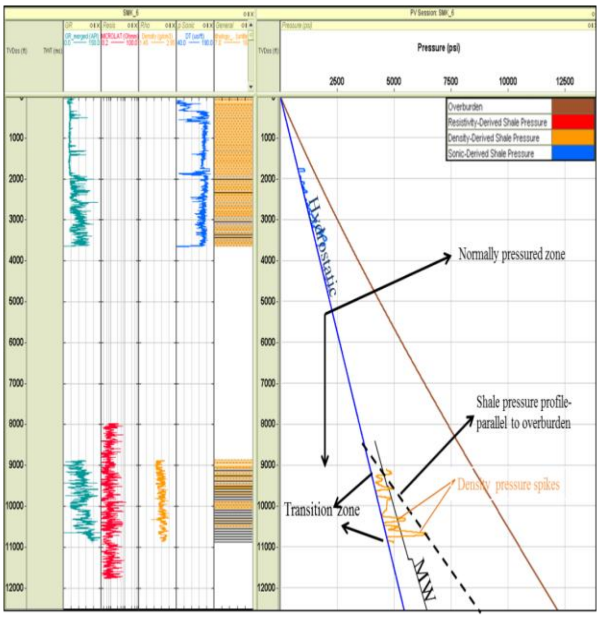

Figure 13a. SMK 6 pore pressure profile showing normal and possible transition zones

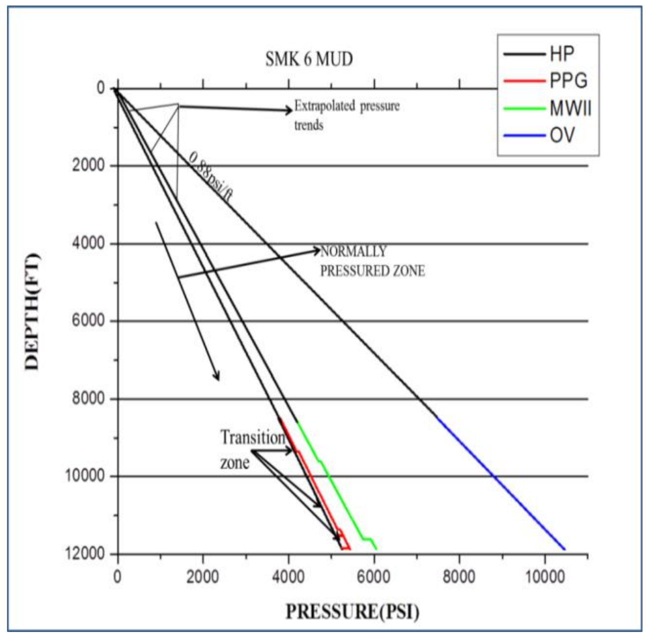

Figure 13b: SMK 6 Dxc Shale pressure profile (HP, PPG, MWII, OV represent hydrostatic, pore pressure, mud weight and overburden gradients)

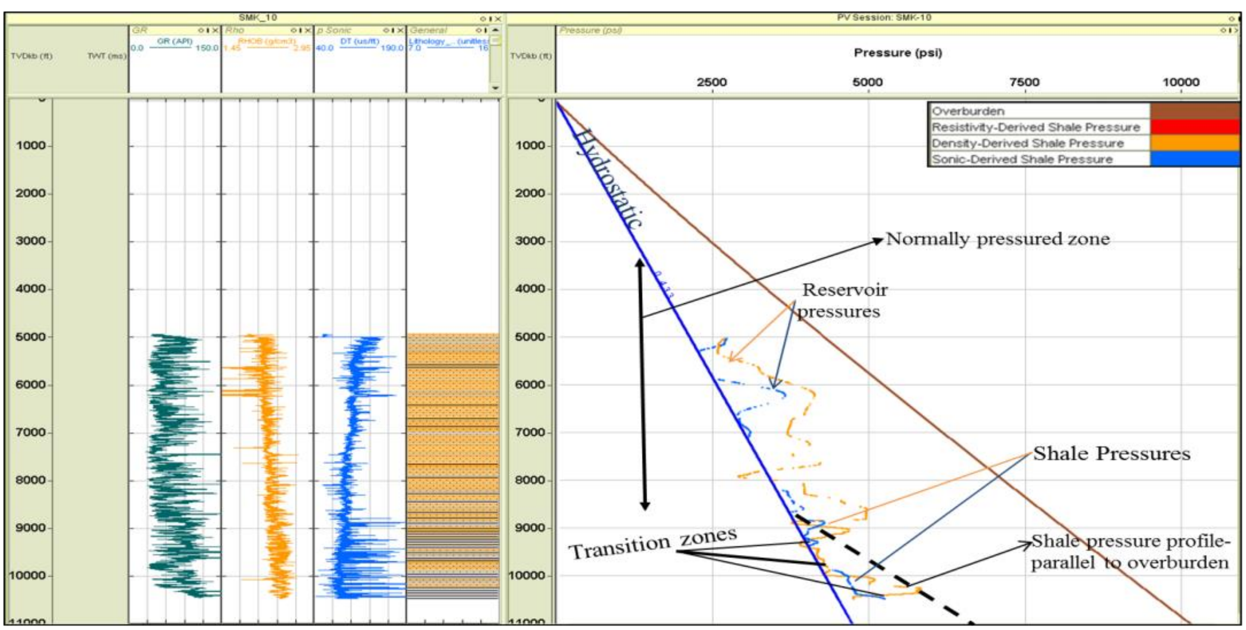

Figure 14. SMK 10 pore pressure profile showing normal and possible transition zones

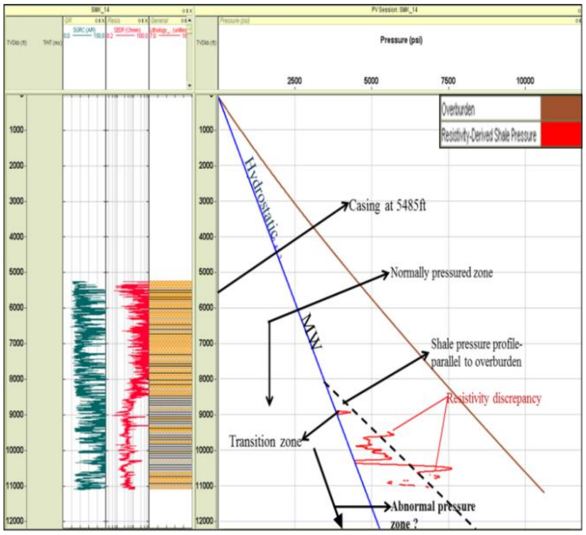

Figure 15a. SMK 14 pressure profile showing normal and transition zones

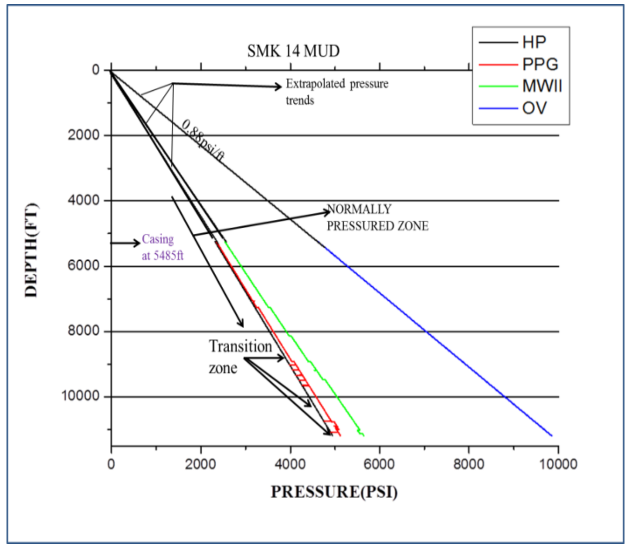

Figure 15b. SMK14 Mud Dxc profile (HP,PPG MWII, OV represent hydrostatic, pore pressure, mud weight and overburden gradients

Table 9. Comparison of wireline/MWD and D-exponent

WELLS	WIRELINE	MWD	Dxc	TREND MATCH	TRANSITION MATCH	OVERPRESSURE MATCH
SMK 1	RES, SON, DENS	NIL	YES	GOOD	GOOD	GOOD
SMK 6	DENS, RES	NIL	YES	GOOD	GOOD(DENS A BIT HIGH BUT GENERALLY SUGGEST A TRANSITION ZONE)	
SMK 12	RES, SON, DENS	NIL	YES	GOOD	GOOD	GOOD (Dxc ALONE FROM 11391FT(3482m) TO FINAL DEPTH
SMK 13	DEN, SON	RES	YES	GOOD	GOOD	GOOD(SON,DENS AND Dxc) POOR(RES TOO HIGH AGAINST Dxc)
SMK 14	RES, NIL	RES	YES	GOOD	POOR (RES TOO HIGH AGAINST Dxc. Dxc SUGGESTS TRANSITION)	

**Normal pore pressure for Onshore Niger Delta = 0.433-0.442 psi/ft or about 8.5ppg (pounds per gallon using a conversion factor of 0.052) and SON, RES and DENS are sonic, resistivity and density based shale derived pressure magnitudes)*

For the over-pressured wells with wireline and mud logs (SMK 1, 12, and 13), comparison of results show excellent matches for pressure magnitudes from sonic derived shale pressure and Dxc at depths of 9000 to 12000ft (Tables 1, 6 and 7). Resistivity derived shale pressures were considerably higher than the corresponding Dxc (11.2/12.9ppg for SMK 1) suggesting a discrepancy possibly due to bad log conditions on resistivity data (Table 1). For the overpressured well with MWD and mud logs (SMK 13), comparison of results showed resistivity derived shale pressures were considerably higher than the corresponding Dxc especially at depths of 12000 and 13000ft (15.6/10.4ppg and 14.6/13.1ppg) suggesting a discrepancy possibly due to bad log conditions affecting resistivity data (Table 7). For the overpressured wells without MWD and mud logs (SMK 8 and 11), comparison of results was done using only wireline logs with sonic and resistivity derived shale pressures showing marked disparity at 9000 and 10000ft for SMK 8 (9.8/15.0ppg and 10.6/14.0ppg)(Table 3) and at 10000ft for SMK 11(10.6/14.0ppg) (Table 5) suggesting a discrepancy possibly due to bad log conditions for the resistivity data. SMK 6 is a transitionally pressured well-showing comparison of results from only density derived shale pressures and Dxc. A similar match was observed for the two methods though not as good as that obtained from sonic derived shale pressures (9.2/8.7ppg) (Table 2). SMK 10 is a normally to transitionally pressured well with only wireline logs. Sonic and density derived shale pressures showed a slight pressure disparity at 9000 and 10000ft (8.7/9.8ppg and 9.0/9.6ppg) (Table 4). SMK 14 is a transitionally pressured well with only MWD and Mud logs and comparison of results showed wide pressure disparity at 10000 and 11000ft from resistivity derived shale pressures(10.2/9.0ppg and 12.3/9.0ppg) (Table 8) possibly as a result of bad log conditions.

Generally, the effectiveness/precision/accuracy of prediction is excellent for wells with sonic derived shale pressures and Dxc at investigated depths (SMKs 1,12 and 13) followed by density derived shale pressures (SMK 6) while resistivity derived shale pressures(both wireline and MWD) are much higher than the corresponding Dxc values particularly below 10000ft for wells investigated(SMK 13,14) while for wells with only wireline logs (SMK 8, 10 and 11), though with no calibrators(pressure data, mud logs),sonic derived shales pressures showed a more realistic estimate of encountered pore pressures followed closely by density while resistivity based shale pressures showed grossly overestimated values. Bad log conditions seemed to be the main factor affecting the resistivity data leading to these spurious shale pressure values. Thus, the sonic derived shale pressures and Dxc shale pressures gave the most reliable estimates which helped to narrow down the window of error and reduce the level of uncertainty in overpressure analysis in the SMK field (Table 9).

4. Conclusion

This study utilized wireline, MWD and mud logs to characterize pore pressures, build confidence and narrow down the window of error in overpressure analysis of the SMK field. Overpressuring in the SMK field is primarily due to Disequilibrium compaction (a loading mechanism) evidenced from velocity – density cross plots which are typical of young, rapidly filling Tertiary sedimentary basins like the Niger and the Nile Deltas. Quantification relied on using standard shale based techniques that rely on porosity/effective stress relationships such as the Eaton and the Equivalent Depth methods compared with Mud log Dxc (D-exponent) shale pressure profiles. Sonic, density and resistivity reversals from the normal trends are analysed for pressure magnitudes and compared with Dxc normal trend reversals. Highly acceptable matches are recorded from the comparison lending credence to the reliability of the prediction using sonic logs, Dxc and some density logs with the spurious log responses for resistivity and some density logs due to bad log conditions. The importance of the Mud log component as a quantifier and a calibrator was evidenced in SMK 12. Logging stopped before 11370ft (casing depth- an indicator of over-pressuring) so only did the D-exponent was used to quantify as well as to safely drill the well (evidenced from three kick zones identified) in the absence any well log.

We would recommend that while a three- way approach is preferred to one or two, incurporating other data sets like 3D Seismic and pressure data like RFTs (Repeat Formation Tester) will go the extra mile in complimenting this work and further build confidence on knowledge of overpressure distribution patterns in the SMK field. Mud logs for SMK 8, 10 and 11 will also further add value to the research as calibrators in building a more robust geopressure model for the field when considering new well sites.

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