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Investigating the Subsurface Pressure Regime of Ada-field in Onshore Niger Delta Basin Nigeria

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Abstract

Pore Pressure Prediction (PPP) has been proven to be more difficult in basins like the Niger Delta where the subsurface pressure system is complex. Failure of PPP practioners to recognize lateral and vertical variations of formation pressure even within the immediate vicinity of local geology had led to greater uncertainty and safety threat in drilling activities. Hence; this work attempted to investigate subsurface pressure pattern in Ada field, on Onshore Niger Delta depositional belt. Wireling logs, mud weights and reservoir pressures from four wells were analysed for this purpose. The overpressure in field is seen to be mild, i.e. below 0.5 psi/ft but it exceeded 0.6 psi/ft at depth ~12000 ft TVDml with overpressure magnitude of 1682 psi. The study revealed the effect of hydrocarbon production in the field as indicated by drained reservoir pressures. The field is seen to have high net-to-gross ratio as it is common with wells that penetrate the Benin Formation. Result shows that reservoir pressures and that of adjacent shales are not equilibrium hence; caution must be taken when using any offset well as a proxy to pore pressure calculation in the studied area. With is information, it will be easier for PPP experts to estimate pore pressures accurately in these intervals and prevent the risk of drilling dry holes in future exploration activities in the area.

Keywords: Pore pressure; Overpressure; Uncertainty; Shale pressure; Niger Delta

Introduction

Pore pressure is defined as the pressure acting on the fluids in the pore spaces of the rock and based on the magnitude; it can be classified as normal, abnormal and subnormal. Pore pressure is said to be abnormal or over- pressured when its value is greater than the hydrostatic pressure; a value which ranges from 0.433 to 0.445 psi/ft in the Niger Delta and it is dependent on water salinity. The hydrostatic value increases onshore and in practice, pore pressure gradient less than 0.5 psi/ft can be termed mild overpressure in Onshore Niger Delta basin.

The causes of overpressure in the Niger Delta has been investigated and attributed mainly to under compaction disequilibrium by several authors however, recent research by Nwozor, Chukwuma and Asedegbega [1-3] have shown that secondary mechanisms (fluid expansion, unloading, clay diagenesis, hydrocarbon generation and gas cracking) are also contributing to overpressure generation.

Given the cost of controlling problems associated with drilling in overpressure or abnormally pressured formation, the oil and gas exploration industry is seriously concerned about knowing the subsurface pressure regime and the cause of the overpressures so as to make informed decision on methods for predicting pressure gradients ahead of the bit. This is even more critical as most of the pore pressure prediction works done are based on assumption and pressure knowledge from shallow hydrostatic reservoirs which has led to underbalanced drilling [3]. To enhance deep and safe drilling in the Niger Delta, it is therefore now imperative to have adequate understanding of the subsurface pressure as rocks or geology varies from one place to another. In that way, uncertainty and the cost of drilling a well to the targeted depth will be reduced. Hence, this research work is a demonstration that even on the same field; overpressure could vary laterally and with depth in a non-uniform pattern across a field. And this could cause the failure of PPP models that assumed that pressure in sands and the adjacent shale are in equilibrium.

Geology of Niger Delta

The Niger Delta is situated in the Gulf of Guinea (Figure 1) and extends throughout the Niger Delta Province as defined by Klett [4]. 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 [5]. These depobelts form one of the largest regressive deltas in the world with an area of some 300,000 km^2 [6], a sediment volume of 500,000 km^3 [7], and a sediment thickness of over 10 km in the basin depocenter [8]. Most of the thick shales are within the Akata Formation, and this section is the habitat of high overpressures and temperatures observed in the onshore area [9].

The Niger Delta Province contains only one identified petroleum system [6,10]. This system is referred to here as the Tertiary Niger Delta (Akata–Agbada) Petroleum System. The maximum extent of the petroleum system coincides with the boundaries of the province (Figure 1). Currently, discoveries have been made in deep/ultra-deep waters offshore but most of this petroleum is in fields that are onshore or on the continental shelf in waters less than 200 m deep (Figure 1), and occurs primarily in large, relatively simple structures.

The studied area lies within the central swamp depobelt onshore Niger Delta as shown with the rectangular box in Figure 2. Deposition of the three formations occurred in each of the five off lapping siliciclastic sedimentation cycles that comprise the Niger Delta. These

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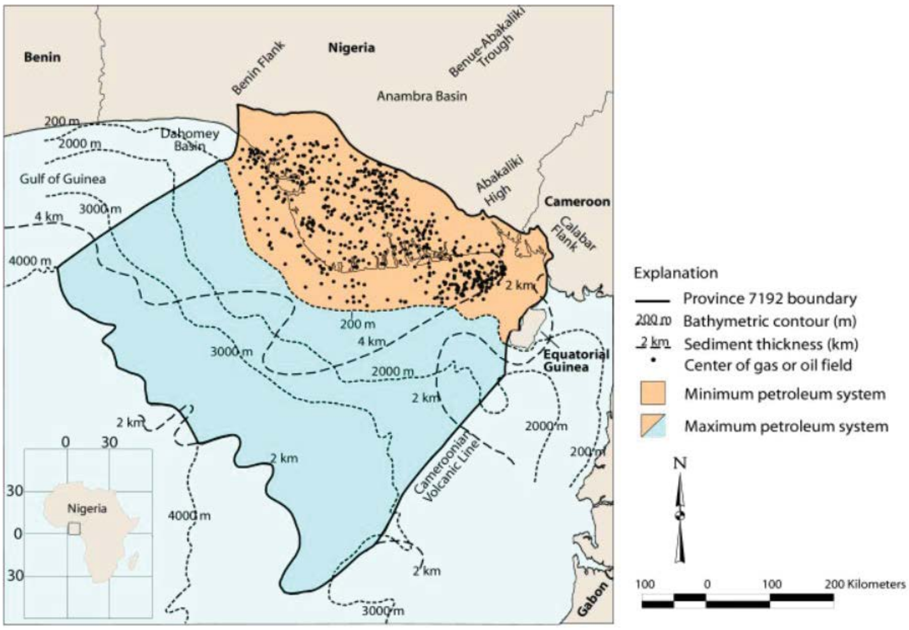

Sources: Tuttle et al., 1996a.

Figure 1: Map of Niger Delta showing Province outline (maximum petroleum system); bounding structural features; minimum petroleum system as defined by oil and gas field center points.

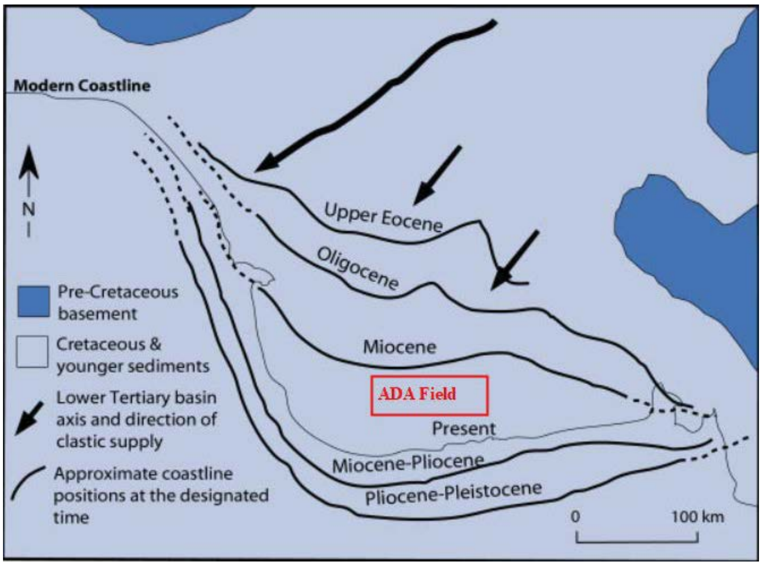

Figure 2: A sketch showing the studied area and different depobelts in Niger Delta. Image modified from Whiteman (1982).

cycles (depobelts) are 30-60 km wide, prograde southwestward 250 km over oceanic crust into the Gulf of Guinea [11], and are defined by synsedimentary faulting that occurred in response to variable rates of subsidence and sediment supply [5]. The interplay of subsidence and supply rates resulted in deposition of discrete depobelts; when further crustal subsidence of the basin could no longer be accommodated, the focus of sediment deposition shifted seaward, forming a new depobelt [5]. Each depobelt is a separate unit that corresponds to a break in regional dip of the delta and is bounded landward by growth faults and seaward by large counter-regional faults or the growth fault of the next seaward belt [5,12]. Five major depobelts are generally recognized, each with its own sedimentation, deformation, and petroleum history (Figure 2).

Doust and Omatsola [5] describe three depobelt provinces based on structure. The northern delta province, which overlies relatively shallow basement, has the oldest growth faults that are generally rotational, evenly spaced, and increased their steepness seaward. The central delta province has depobelts with well-defined structures such as successively deeper rollover crests that shift seaward for any given growth fault. Last, the distal delta province is the most structurally complex due to internal gravity tectonics on the modern continental slope.

Materials and Methods

The analysis was carried out using four wells from Ada field that have wire line logs (gamma ray, resistivity, density and sonic log. The lithology was defined by generating shale volume from Gamma ray log as an indicator of sands and shales intervals. The given direct pressure data or Measured Pore Pressure (MPP) data were first quality-checked based on logger engineer's observations and comments in the End- Of-Well Report (EOWR). A depth plot was made alongside gamma-ray to pin-point that the source depth-points are actually in the sands since measurements can only be obtained in permeable sands. Considering that some radioactive sands could exist in the Niger Delta, identified sand intervals were cross-checked in the composite logs.

S/N	Well Name	Depth (ft)	MPP (psi)	Overpressure (psi)
1	ADA_001	8414	3750	111.591
2	ADA_001	10476	4714	188.931
3	ADA_001	10561	5000	438.381
4	ADA_001	10882	5400	700.351
5	ADA_001	10986	5250	505.631
6	ADA_001	11240	5500	646.411
7	ADA_001	11521	6500	1525.581
8	ADA_001	11627	6511	1491.001
9	ADA_002	7558.27	3085.304	164.752
10	ADA_003	10164	5100	677.116
11	ADA_003	11780	6800	1682.236
12	ADA_3ST1	7063	2760	-335.096
13	ADA_3ST1	7473	3170	-101.396
14	ADA_3ST1	7760	3316	-78.806
15	ADA_3ST1	7865	2697	-742.956
16	ADA_3ST1	10036	4450	76.514
17	ADA_3ST1	10249	4457	-8.076
18	ADA_3ST1	10449	4791	239.924

Table 1: Measured Pore Pressure (MPP) data in the field.

Pressure data and mud weight were plotted against depth and displayed with the hydrostatic and overburden gradients and subsequently interpreted for the results discussed in this study. Through depth plots of pressure and overpressure, we aim to note the presence of overpressures and their connectivity across the investigated wells.

Data analysis

The overpressure magnitudes determination was informed by the defined hydrostatic gradient (0.445 psi/ft). This was done by extracting measured pore pressures (Table 1) and calculating amounts of overpressure in measured intervals of the wells.

Results and Discussion

The values of direct measured pressures displayed on the lithology track in Figure 3 shows an increased with depth until ~11000 ft TVDml where the pressure dropped from 6400 to 5250 psi (i.e., about 1150 psi pressure difference). Although, the shales in between the sands appear to be acting as a seal so the reservoir may be draining individually by

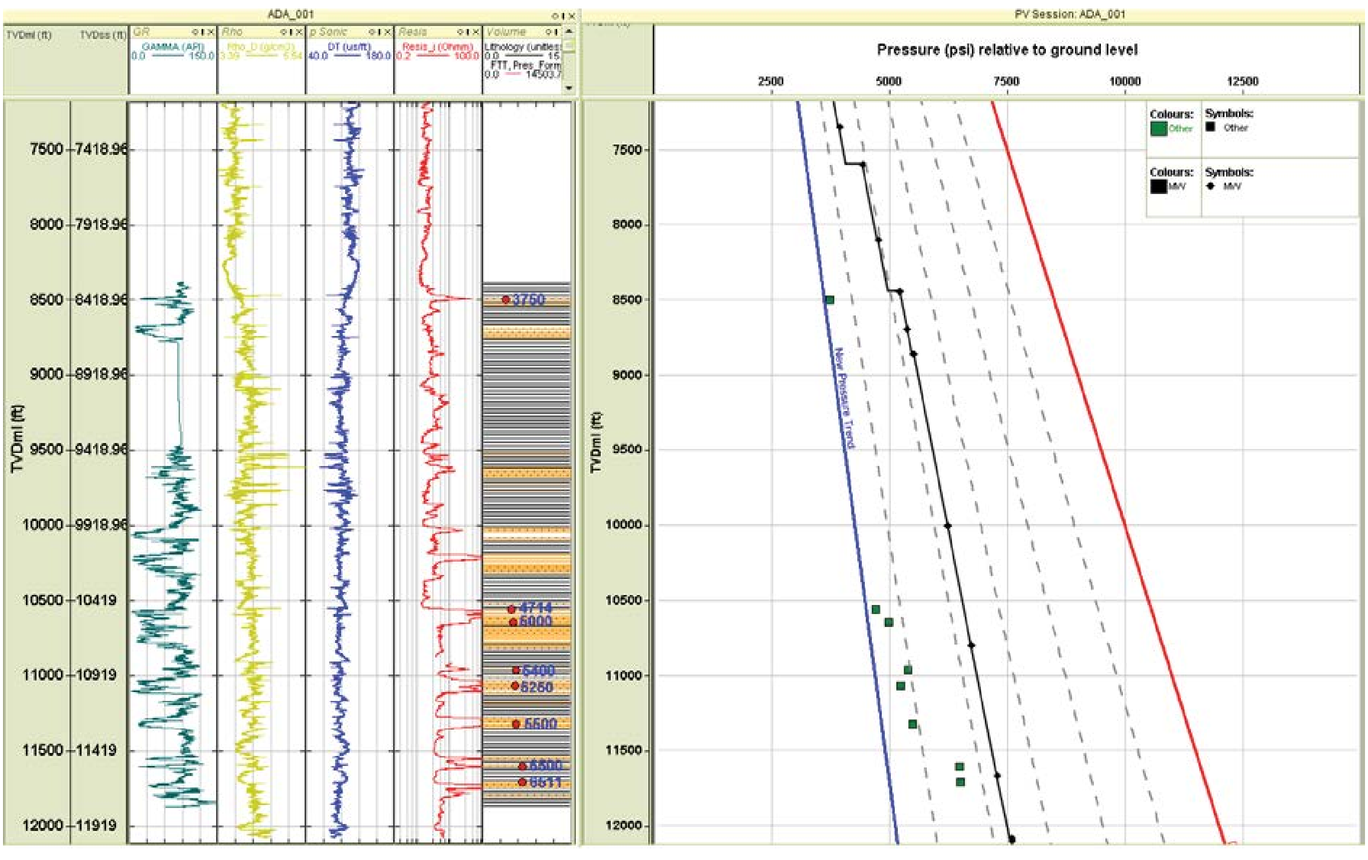

Figure 3: A plot of well ADA-001 showing the well logs; lithology; hydrostat (blue line); direct pressure (green data point); mudweight (black line) and overburden gradient (red line).

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production effect. This is especially so, when there is no evidence of hydraulic connectivity. After this interval, there seems to be pressure build (6500 psi) and the overpressure reaching 1525 psi at ~11700 ft TVDml downwards as analysed in Table 1 above and Figure 3. These reservoirs in well ADA-001 are also indicated by the resistivity log increase at these intervals.

Unlike well ADA-001 that is shale rich, the net to gross in well ADA-002 is high and the only recorded pressure point appears drained and falls below the defined hydrostatic gradient with estimated overpressure magnitude of 164 psi. Similarly, well ADA-003 has high net-to-gross ratio with observed pressure ramp at 10500 ft TVDml and increases with depth (Figure 4). The pressure at depth exceeded 0.6 psi/ft with overpressure magnitude of ~1682 psi at 11800 ft TVDml as indicated by the mud weight and the pressure point (green coloured point) in Figure 4 and Table 1. Contrarily, in a near side tracked well ADA-3ST1, the reservoirs pressures are observed to be drained (Figure 5) just as was observed in well ADA-002 in Figure 6. It shows that, the reservoirs in this field are lateral connected and hydrocarbon production would have drained the sands pressure as revealed by the depleted point. Pressure depletion causes the internal stress within the reservoir rock to increase. This change produces changes in the grain arrangement and other phenomena that ultimately cause the pore volume of the rock to decrease. The contraction of the reservoir pore volume aids in expelling fluids from the reservoir.

The wells analysed penetrated the sand-rich Benin Formation and this sand dominated unconsolidated sediments maintains free hydraulic communication with the surface and are such in normal hydrostatic equilibrium [13]. The development of massive regional shales in sections of Agbada Formation begins to alter this normal pressure state with the implication that pockets of encased sands in the sand-shale succession could exhibit various degrees of rising fluid pressures.

The cross correlation panel in Figure 7 reveals further that, there is no clear pattern of overpressure variation in ADA field as attested to by negative overpressure magnitudes recorded in well ADA-3ST1. Operational experience in the Niger Delta gives insight that its pore pressure system is reflective of its stratigraphy and structuration. In areas where the reservoir pressures are depleted either through hydrocarbon production and hydraulic head leakage through complex but minor faulting system, the stress regime is also altered. The effects of pressure depletion on horizontal stresses cannot be ignored as; drilling high angle or horizontal wells through depleted reservoirs induces a lot of challenges in well planning and drilling management. According to Addis [14-16], stress measurements within hydrocarbon reservoir show that the least horizontal stress (fracture gradient) decreases with declining reservoir pressure in the depleted reservoir. Therefore, quantifying pressures in depleted or drained sands is its application to the efficient drilling of future prospects in matured fields like Ada field.

Over Burden and NCT models were built in ADA field (Figure 8a, 8b). Density log was derived for some wells using Gardner's equation [17]. There was an increase between 6000ft to 10000ft. This shows that wells are likely over pressured. From 10100ft to 12000ft there is decrease in pressure (Figure 8a). There was increase in pressure from 6000ft to

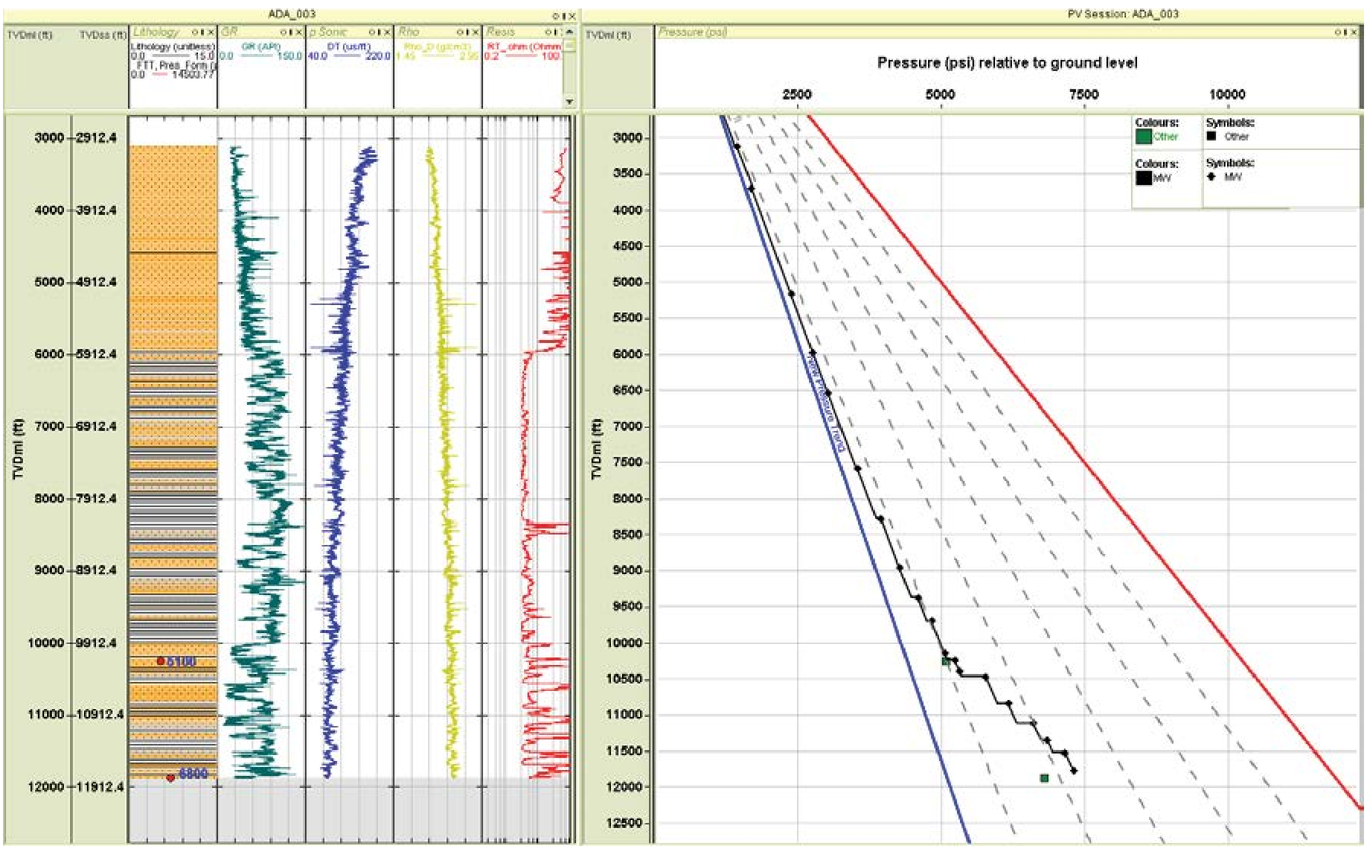

Figure 4: A plot of well ADA-003 showing the well logs; lithology; hydrostat (blue line); direct pressure (green data point); mudweight (black line) and overburden gradient (red line).

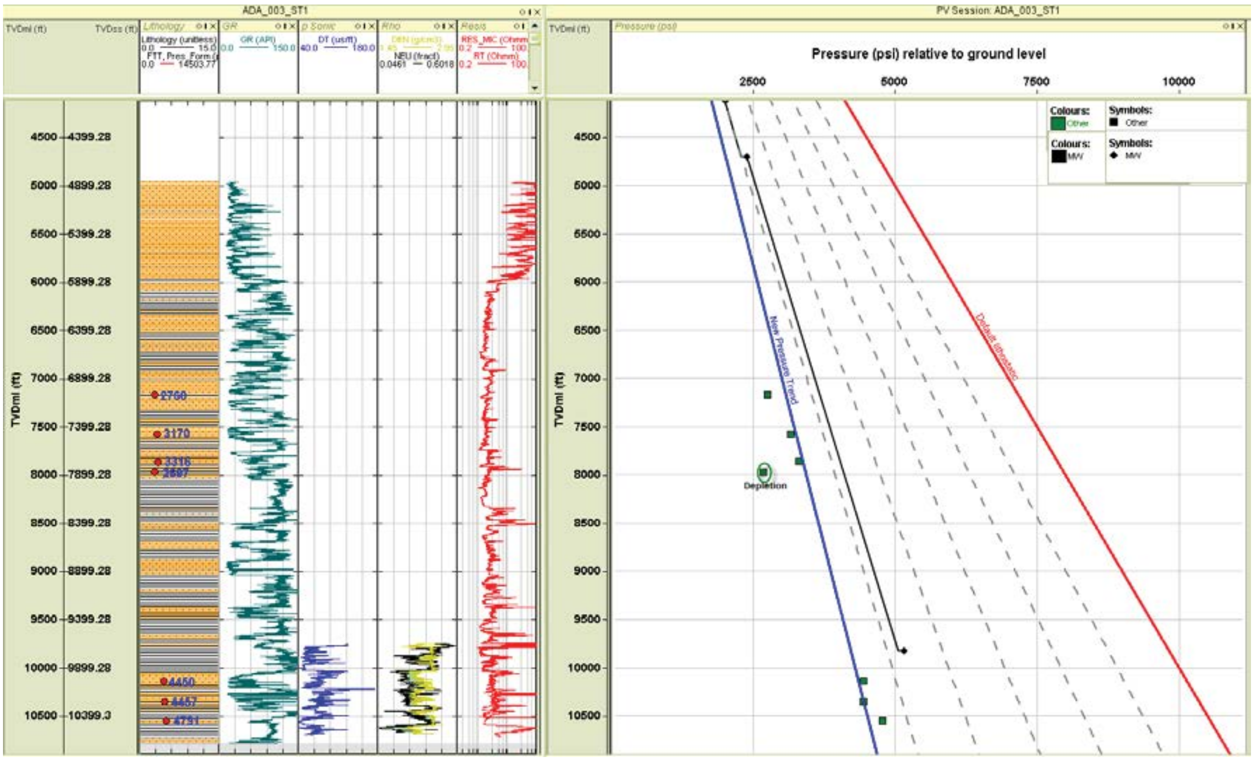

Figure 5: A plot of well ADA-003ST1 showing the well logs; lithology; hydrostat (blue line); direct pressure (green data point); mudweight (black line) and overburden gradient (red line).

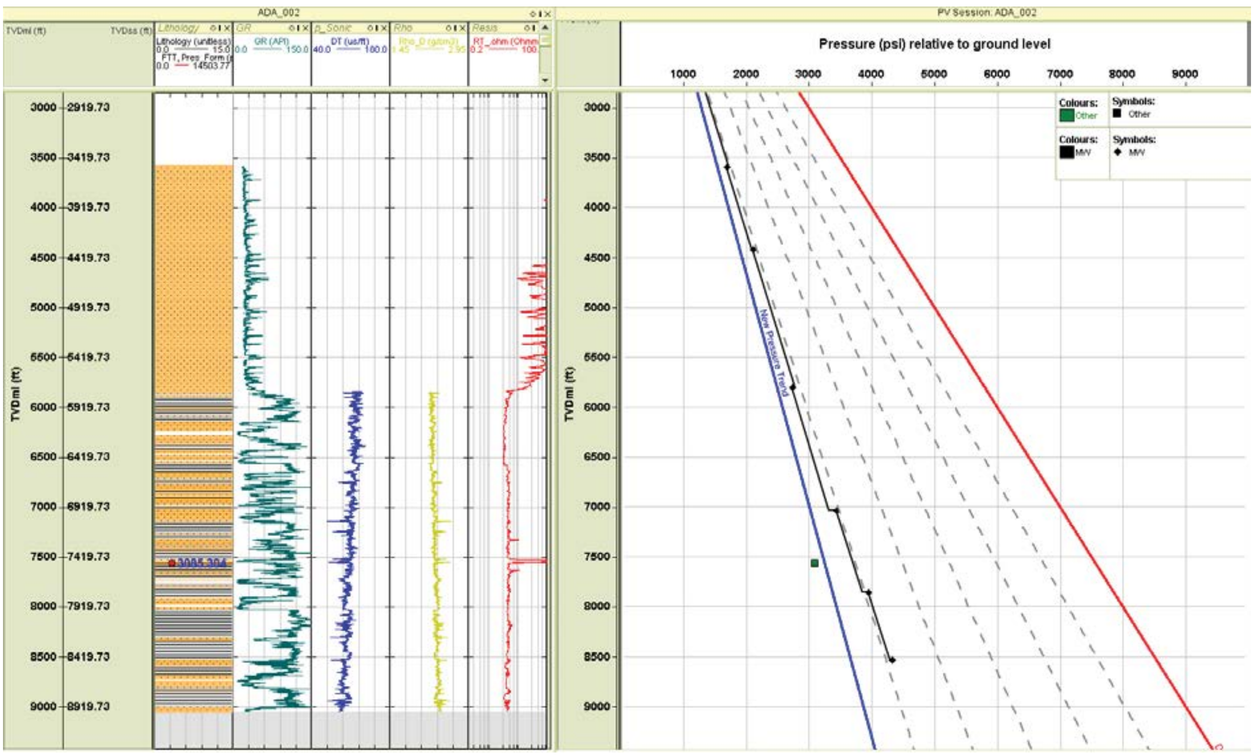

Figure 6: A plot of well ADA-002 showing the well logs; lithology; hydrostat (blue line); direct pressure (green data point); mudweight (black line) and overburden gradient (red line).

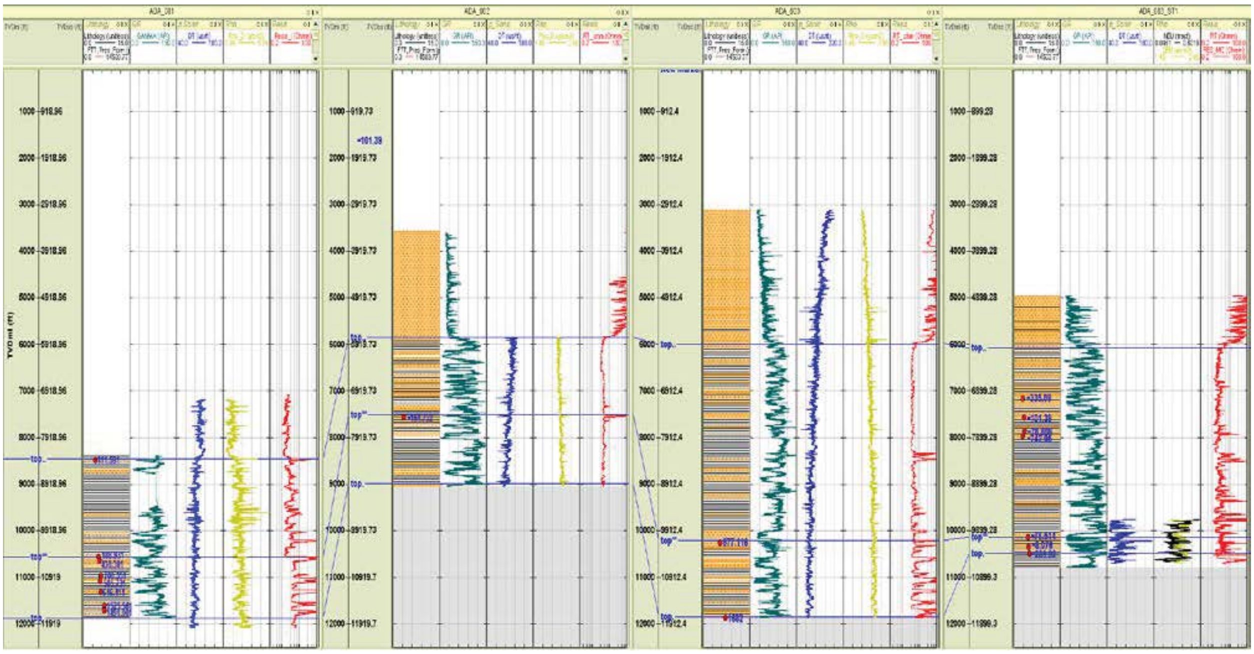

Figure 7: A correlation panel showing the variation of overpressure magnitudes across the four wells analysed.

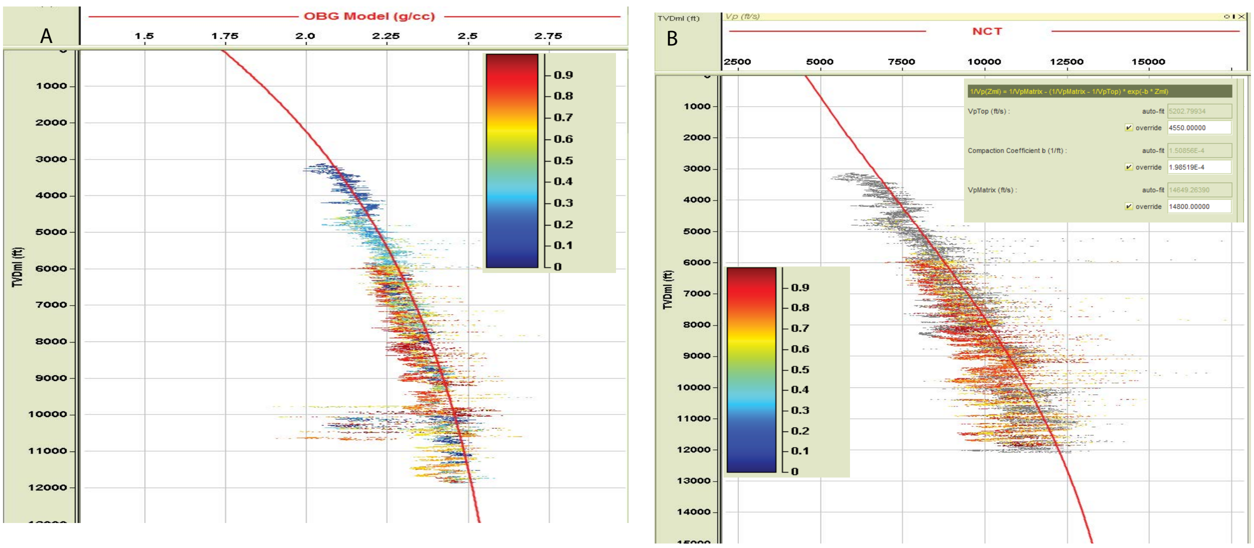

Figure 8: a) Over Burden Model built in ADA Field. b) Normal Compaction Trend model built in ADA field.

10000ft. VPtop was calculated, Compaction coefficient and VPMatrix was achieved (Figure 8b). The over burden model and NCT model will be tested on other fields in subsequent research.

Summary and Conclusion

This study has revealed that the subsurface pressure regime in Ada field is not uniform and even more complicated by hydrocarbon production effect as the sands pressures appear drained thus, are not in equilibrium with that of the adjacent shales. This holds true that as hydrocarbon is extracted reservoir compaction from pressure depletion is inevitable and can lead to a loss in well productivity and increase the probability of well failure. While reservoir compaction can be advantageous to recovery by providing extra energy for production, most often compaction causes many field operating problems. Similarly, drained or depleted reservoirs can be misleading and could lead to high level of uncertainty in PPP, thereby creating a drilling challenge to drillers especially, if the adjacent shales are highly overpressured. Many PPP experts are able to forecast pore pressures with ease in these intervals because they are mainly as a result of stress-controlled under compaction. Complexities to pressure prediction often arise when overpressured fluids have been remobilised through the numerous fault systems and connected channel complexes in the area with the implication of unexpected drilling challenges, costly well abandonments and unproductive reservoirs. In Ada field, maximum magnitude of overpressure estimated is ~0.6 psi/ft at greater depth of ~12000 ft TVDml which can be classified as mild overpressure. However, previous studies had revealed the likelihood of penetrating the massive hard overpressured organic-rich shales that are believed to feed hydrocarbons to encased sands and reservoirs of the Agbada Formation at deep. Hence; further drilling activities in matured fields with similar subsurface pressure system like Ada field, should involve a robust geo-mechanical model to help identify drained sands and compaction issues at the field planning stage. Sustaining it throughout the field development and production phases would enhance reservoir understanding and predict the effect of compaction on rate of production and completion integrity.

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