

Application of Well Log Data in Overpressure Identification – A Guide to Hydrocarbon Exploration Onshore Niger Delta

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ABSTRACT

Proper detection and prediction of overpressure zones is one of the biggest challenges facing the oil industry in particular as exploration moves into deep water environs. The origin of overpressure and its effects on the petroleum systems are complex, difficult to quantify and may result in kicks and/or blow-outs if not adequately detected, predicted and accounted for before and during drilling. The main thrust of this paper is overpressure detection using well log and check-shot data from three wells drilled onshore Niger Delta which were sourced from the Department of Petroleum Resources. These data sets were interpreted qualitatively using RokDoc (powered by Ikon Science) and Microsoft Excel software for the purpose of overpressure detection, correlation and normal compaction trend (NCT) analyses. The results revealed five possible continuous overpressure zones intercalated within probable hydrocarbon bearing reservoirs between a depth of 6,147.50 ft (1,873.76 m) and 9,998.66 ft (3,047.59 m) across the three wells investigated. These zones with thicknesses varying between 35.88 ft (10.94 m) and 586.06 ft (178.63 m) showed a marked increase in interval transit time at the onset of the overpressure and eventually continue to decrease at the base of the overpressure zones. The interval transit time values vary from 337.89 μ s/m to 383.73 μ s/m. A plot of average and interval velocities calculated from check-shot data revealed a distinct NCT with depth while the plot of sonic velocity decreases at intervals indicating an abnormal compaction trend. This was used to ascertain the possible overpressure zones. This study revealed that overpressure zones attributed to under-compaction are present onshore Niger Delta.

Keywords -- Formation, Compaction, Overpressure, Log, Niger Delta

1. INTRODUCTION

Hydrocarbon, which serves as the backbone of the world's economy today, has been predicted to be the major source of energy into the foreseeable future. This is because it produced more quantity of energy per unit volume than other sources of energy. However, one of the major challenges associated with exploration and exploitation of oil reserves is drilling into overpressure zones which may occur above and or below hydrocarbon bearing zones in the Niger Delta (Evamy *et al.*, 1978). This may result in kicks and/or blow-out if not adequately detected, predicted or accounted for before and during drilling.

Abnormally pressured rocks are typical of many sedimentary basins worldwide with formations ranging in age from the Cenozoic era (Pleistocene age) to as old as the Paleozoic era (Cambrian age) occurring in a wide range of geological conditions. Hunt (1990) cited over 180 basins in which overpressure zones have been identified including basins from the America, Europe, Middle East, Far East and Africa. Overpressure zones may occur at a few hundred meters below the surface or at depths exceeding 6,100 m in shale-sand sequences and/or carbonate-evaporite sections (Petroconsultants, 1996; Alao *et al.*, 2014).

The concept of pore-pressure detection using wireline logs help in planning the drilling process (i.e. casing and mud

weight design) to control potentially dangerous abnormally pressured zone. This method exploits the fact that a geo-pressured formation exhibits several of the following properties when compared with normally pressured section at the same depth

(Schlumberger, 1989). High porosity, lower bulk density, lower effective stress, higher temperatures and lower interval velocities.

2. LOCATION OF THE STUDY AREA

The data analyzed for this study were from wells drilled in the onshore area of the Niger Delta region, southern Nigeria by Shell Petroleum Development Company of Nigeria (SPDC). The study area is situated between

Latitude 4°N and 6°N and Longitude 3°E and 9°E (Figure 1).

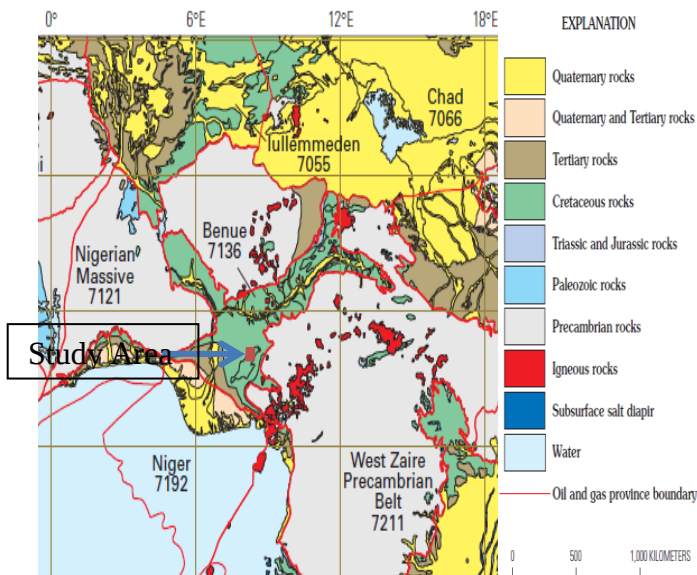


Fig 1: Map of the Nigeria Sedimentary Basin Showing the Study Area Arrowed (Petroconsultants, 1996).

3. GEOLOGY OF THE NIGER DELTA BASIN

The Niger Delta region has been a scene of intense study in the recent past because of its economic potential as a petroliferous province and also for its attendant overpressure problem. It is the most important sedimentary basin in Nigeria from the point of view both of size and thickness of sediments, and from economic point of view as its petroleum reserves provide a large part of the country's foreign exchange earnings. Several papers have discussed various aspects of the Niger Delta (e.g. Allen, 1965, 1970; Stoneley, 1966; Frankl and Cordry, 1967; Short and Stauble, 1967; Weber and Daukoru,

1975; Evamy *et al.*, 1978; Ekweozor and Okoye, 1980; Ejedawe, 1981; Ejedawe and Okoh, 1981; Ejedawe *et al.*, 1984; Nwachukwu and Chukwura, 1986).

However, the Tertiary lithostratigraphy sequence of the Niger Delta consists of the marine Akata Formation which is a continuous shale unit (oldest), the paralic Agbada Formation which is an alternating sequence of sandstone and shale and the continental Benin Formation which consist of predominantly massive, highly porous, freshwater-bearing sandstone with local thin shale interbeds considered to be of braided stream origin (youngest). They make up an overall regressive clastic sequence of about 30,000 ft to 39,000 ft (9,000 m to 12,000 m) thick (Evamy *et al.*, 1978) and are stratigraphically super-imposed in space and time (Figure 2). These formations range in age from Eocene to Holocene.

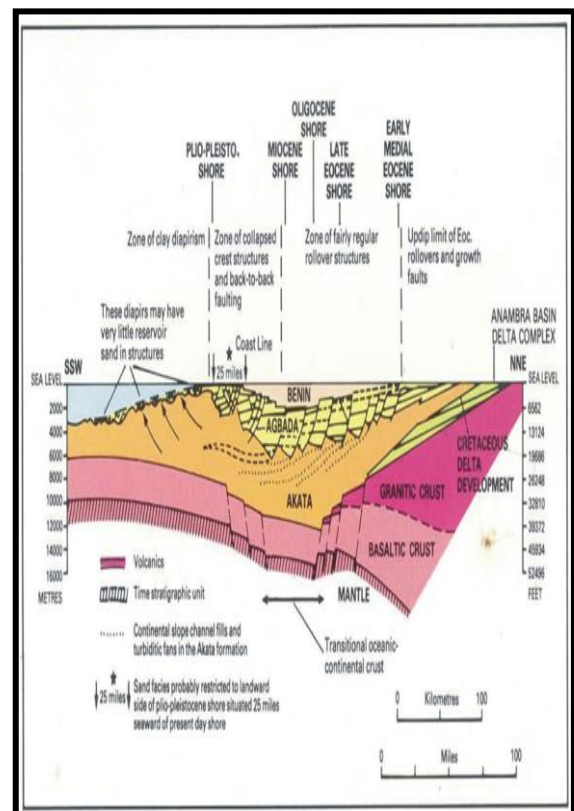


Fig 2: A generalized Dip Section of the Niger Delta Detailing the Subsurface Formations and the Structural Styles (Modified After Weber, 1971).

4. CONCEPT OF ABNORMAL PRESSURES

4.1 Overpressure

Overpressure is defined as any pressure which exceeds the hydrostatic pressure of a column of water or formation brine (Dickinson, 1953 and Figure 3). Another way to view overpressure, in terms of the dynamics of subsurface fluid

flow, is the inability of formation fluids to escape at a rate which allows equilibrium with hydrostatic pressure, calculated from a pressure gradient which varies from 0.433 psi/ft (9.71 kPa/m) for fresh water to about 0.51 psi/ft (11.44 kPa/m) for saturated brine.

Overpressure is a disequilibrium state resulting from fluid retention and one of the primary controls on the presence and distribution of overpressure is therefore permeability, the rock attribute which controls seal behaviour.

Many of the world's basins contain overpressured reservoir, Hunt (1990) cited 180 basins, including basins from the America, Africa, Europe, Middle East, Far East and Australia, where overpressure has been recognized. Overpressure is found in carbonate and clastic reservoirs and in rocks deposited in the full range of sedimentary environments. Hydrocarbons are often associated with overpressures but not exclusively so and there does not seem to be a universal relationship between overpressure and hydrocarbon traps (Swarbrick and Osborne, 1998).

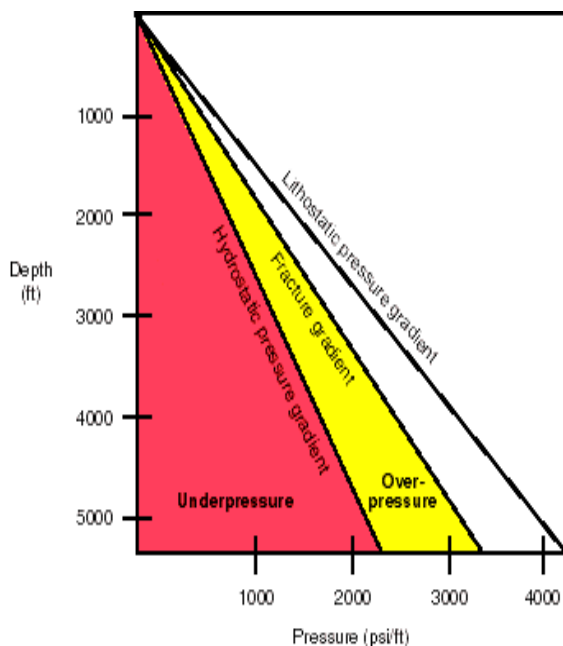


Fig 3: Relationship between Pressure Distributions and Depth (After Petroconsultants, 1996).

Note: Rocks whose pressures plot between the hydrostatic and lithostatic gradients are termed “overpressured” and those whose pressures are less than hydrostatic are “under pressured”.

4.2 Underpressure

Underpressure exists when pore pressure is significantly lower than the hydrostatic pressure (Figure 3). Underpressure results from depletion during oil and gas production. Fewer examples

of underpressure are documented in comparison with overpressure, a factor which Hunt (1990) attributes to the difficulty of recognizing underpressure during conventional drilling operations. Naturally underpressure reservoirs (as opposed to underpressure during depletion) have not been widely recognized, being restricted mainly to interior basins which have undergone uplift and temperature reduction. However, naturally underpressure reservoirs have been described from a number of basins particularly in Canada and USA. In each of the above case histories, the basin has been uplifted and contains gas-bearing reservoirs which have experienced reducing temperatures. Law and Dickinson (1985) and Grigg (1994) believe underpressure reservoirs today have been overpressured in the past.

According to a survey of published literature on abnormal pressures, compaction disequilibrium and hydrocarbon generation are the two most commonly cited causes of abnormally high pressure in petroleum provinces. In young (Tertiary) deltaic sequence (such as the Niger Delta), compaction disequilibrium is the dominant cause of abnormal high pressure (Law and Spencer, 1998).

For sediment to compact, pore water must be expelled. However, if sedimentation is rapid compared to the time required for fluid to be expelled from the pore spaces or if seals that prevent dewatering and compaction form during burial, over time and with increasing compaction due to overburden pressure, grain to grain contact between solids is not established and the fluids in the pores become compressed, overpressured and support part of the overburden load (Figure 4).

5. OVERPRESSURE DETECTION THEORY

Overpressure detection is based on the premise that pore pressure affects compaction – dependent geophysical properties such as density, resistivity and sonic velocity. Shales are the preferred lithology for pore pressure interpretation because they are more responsive to overpressure than most rock types. Consequently, overpressure detection in this research has been centered on shale deformation behavior using Sonic logs and Gamma Ray logs.

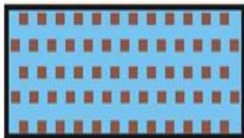
Figure 6 shows the expected trend in the density, resistivity and sonic logs in an overpressure zone. A deflection to the left

is noticed in the log signature of the resistivity, sonic velocity and density logs at the onset of an overpressure zone, labeled “Abnormal”. The “Normal” trend is an increase in resistivity, sonic velocity, and density with depth.

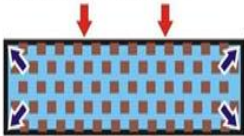
During burial, under normal pressure conditions, the effective stress continually increases with depth. Density and sonic velocity increases normally with depth except for resistivity values, which vary in accordance with temperature and salinity. The depth profile that a compaction-dependent geophysical property would follow during burial under normal pressure conditions is termed its normal trend (ENPL, 2001).

Overpressure prevents the effective stress from increasing as rapidly as it would during burial under normal pressure conditions. Consequently, the onset of pressure (top of overpressure) generally occurs where a compaction-dependent geophysical property first departs from its “normal” trend as shown in Figure 5. On the depth plots, classic signs of under-compaction are density, resistivity and sonic velocity data that either continue increasing or remain constant after they depart from their normal trends (Figure 5).

(a). At deposition: very fine sediment grains in water



(b). With increasing overburden load: water cannot escape



(c). Disequilibrium compaction: load shared between pore fluid & grains, low vertical effective stress

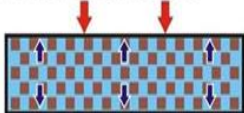


Fig 4: Disequilibrium Compaction. (a) Deposition as a slurry of water and very fine-grained sediment e.g. muds and shales. (b) With increasing load the water cannot escape due to the fine grain size and/or the rapidity of loading i.e. high deposition rates. (c) The load of the overburden (red arrows) is shared between the grains (brown) and the pore fluid (blue arrows) (Ikon Science, 2010)

6. RESULTS AND DISCUSSION

Data obtained from three wells, each from different field, (Ajokpori_001, Ebubu_007 and Onne_001) which were drilled in OML11 onshore Niger Delta, Nigeria were analyzed and interpreted for this study. The wells all lie between Northings 518,880 m to 523,373 m and Eastings 80,073 m to 91,334 m (Figure 6). A suite of borehole data comprising Spontaneous Potential log (SP), Gamma Ray log (GR), Borehole compensated sonic log (BCSL), compensated Formation density log (FDC) and a number of Resistivity logs were sourced from the data base of the Department of Geology, Obafemi Awolowo University, Ile-Ife. The correlation of sands and overpressured zones was carried out using Rokdoc® 5.4.4 software (Powered by Ikon Science). Microsoft® Excel 2010 (Microsoft ® Corporation) software was used to make a plot of average velocities, interval velocities, sonic velocities and gamma ray log data against depth.

6.1 Petrophysical Analysis

Intercalation of sand and shale sequence was observed in the study area between depths of about 4,143.53 ft in Ajokpori-001 to about 10,333.55 ft in Onne-001. It was evident that the lithology in the study area from the gamma ray and SP logs available is one of sand-shale sequence, their differences lie in the variations in the depth at which these sand/shale sequences occur in individual wells.

Six (6) prospective reservoir sand units (SAND 1 to SAND 6) intercalating with shales were identified and correlated within the three (3) wells (Figure 7). Petrophysical parameters were computed to characterize four probable hydrocarbon-bearing sand units of interest (SAND 2, SAND 3, SAND 5 and SAND 6) quantitatively. The Volume of Shale (V_{shale}), Water Saturation (S_w), Hydrocarbon Saturation (S_h), Effective Porosity ($\emptyset$) and the Movable Hydrocarbon Index (MHI) were computed for these reservoir sand units (Table 1).

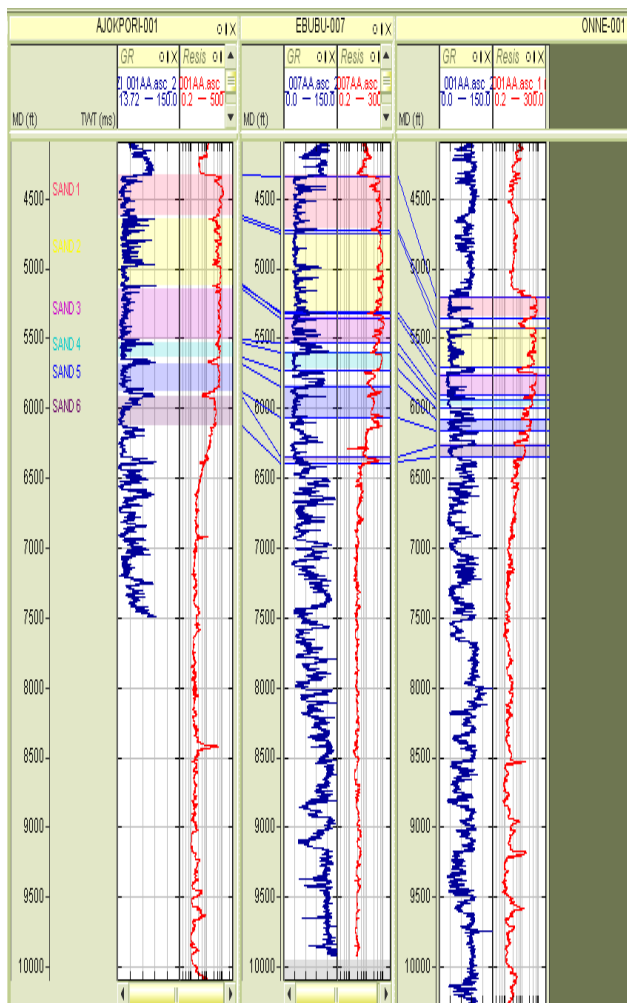


Fig 7: Sand Correlation Across the Studied Wells

The thickness values obtained ranges from 68.90 ft (13.13 m) to 284.22 ft (86.63 m) in Onne-001, and the volume of shale varies from 10.17 % in SAND 05 to 13.37 % in SAND 06, making the sand units a clean sand unit since the volume of shale is between the 10 – 15 % for clean sand units (Hilchie, 1978). The hydrocarbon saturation ranges from 58.69 % in SAND 06 to 82.97 % in SAND 03. The MHI of the hydrocarbon bearing sand units of this well lies between 0.24 in SAND 03 to 0.49 in SAND 06. A MHI of 1 implies that no hydrocarbons were moved during invasion. If the MHI is less than 0.7 for sandstone, or less than 0.6 for carbonates, then hydrocarbon were moved during invasion (Schlumberger, 1972). The values of MHI computed for the hydrocarbon bearing sands show that the hydrocarbons were moved during invasion. This indicates high mobility of the hydrocarbon within the reservoir pores. The effective porosity values obtained falls within the 28 % to 35 % documented for the Agbada Formation (Schlumberger, 1989). This distinct trend has been found to characterize the wells used for this study;

the only difference lies in their thicknesses and depth of occurrence.

The petrophysical parameters computed for each of the reservoir sand units delineated shows that the study area is a good hydrocarbon prospect and its worth drilling if overpressured zones mapped are avoided and/or controlled during drilling.

6.2 Overpressure Identification

Overpressured shales are known to be present in Akata Formation of the Niger Delta, but streaks of these overpressured shales also occur in the Agbada Formation. The overpressured zones were identified at well locations based on their response to the sonic log and the lithologic logs (Gamma Ray log). Transit time (which is what sonic log measures) decreases with depth under normal pressure condition, a reversal is noticed in form of a sudden increase in the transit time in overpressured shale correlated from the Gamma Ray log.

Five (5) possible continuous overpressure zones were revealed, the various depth at which overpressure zones begins to occur are marked off by the tops and the bottoms mark the depth at which the overpressure zones begin to terminate (Figure 8). Thus it was possible to estimate the thicknesses of the five (5) possible overpressure zones. The five (5) detected overpressure zones and the various depths at which they occur in the wells within the study area as well as their various thicknesses are shown in Table 2. A plot of average velocity and interval velocity calculated from the check shot data together with the sonic velocity and gamma ray reading was plotted against depth using the scatter chat (Table 3 and Figure 9).

This plot shows a general trend of average velocity values and interval velocity values increasing with increasing depth in ONNE_001. This is known to be the normal compaction trend. The sonic velocity log however shows decrease at various depths in the well thus indicating an abnormal compaction trend. This was found to be the trend across the other wells.

The abrupt decrease in sonic velocity values employed together with the Gamma Ray log was used to ascertain the five possible overpressured zones identified with the RokDoc software.

7. CONCLUSION

Thus, the result of our findings revealed the existence of anomalous overpressure zones in the study area investigated. The petrophysical characteristics and pattern of the overpressure zones mapped suggest a similar relationship to the petroliferous basins elsewhere in the world. This study has shown that overpressure zones ranging in thickness between 35.88 ft (10.94 m) in ONNE-001 to 586.06 ft (178.63 m) in EBUBU-007 exist. The existence of these zones is attributed

to possibly under-compaction in the onshore parts of the Niger Delta ranging in depth from 6,147.50 ft (1,873.76 m) in AJOKPORI-001 to 9,998.66 ft (3,047.59 m) in ONNE-001. The shales which are believed to be overpressured exhibits some distinct properties when compared with normally pressured section at the same depth such as high interval transit time. This material must be adequately accounted for before and during drilling in order to prevent kicks and/or blow-outs.

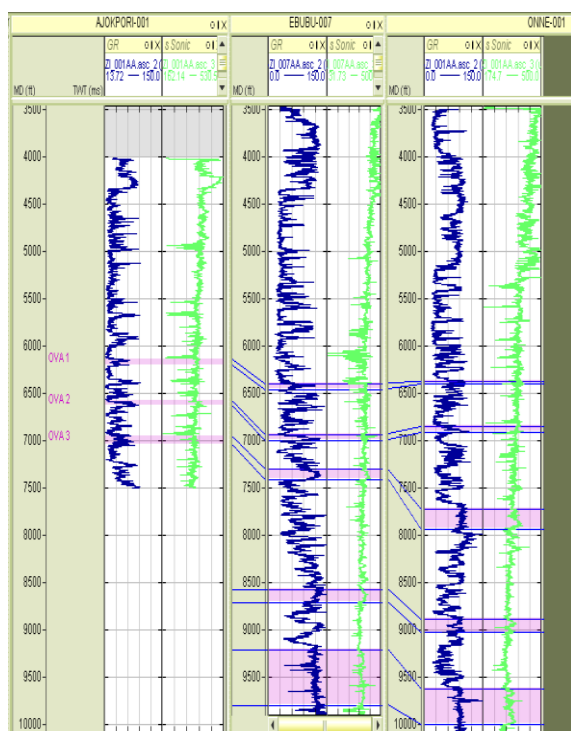


Fig 8: Stratigraphic Correlation of the Overpressured Zones
(Produced with RokDoc®5.4.4)

8. ACKNOWLEDGEMENTS

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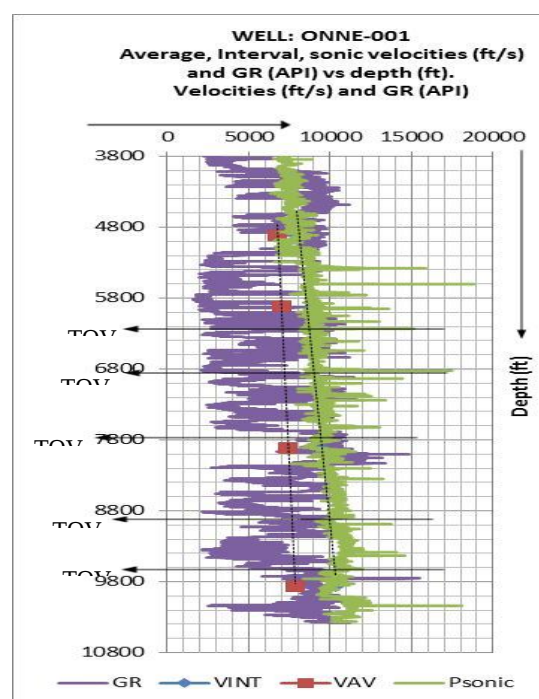


Fig 9: Comparison of Velocities from Sonic Log and Check Shot with Gamma Ray Log for Onne-001
(Produced with Microsoft Excel, 2010)

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Table 1: Petrophysical parameters calculated for ONNE-001

	SAND TOP (m/ft)	SAND BASE (m/ft)	GROSS SAND (m/ft)	V _{shale} (%)	S _w (%)	S _h (%)	MHI (%)	Ø (%)
SAND 02	1,651.15 5,417.94	1,737.78 5,704.98	86.63 284.22	13.17	26.13	73.87	0.34	35.45
SAND 03	1,753.53 5,764.78	1,800.78 5,908.30	47.25 155.02	12.10	17.03	82.97	0.24	31.49
SAND 05	1,853.28 6,075.74	1,874.28 6,159.46	21.00 68.90	10.17	20.28	79.72	0.27	34.13
SAND 06	1,908.41 6,255.15	1,934.66 6,350.83	26.25 86.12	13.37	41.31	58.69	0.49	34.14

Table 2a: Depth to Top and Base of Overpressure and Corresponding Thickness for AJOKPORI-001 Well.

	Top (m/ft)	Base (m/ft)	Thickness (m/ft)
OVA 1	1,873.76/6,147.50	1,888.34/6,195.34	14.58/47.84
OVA 2	2,001.35/6,566.11	2,019.58/6,625.91	18.23/59.80
OVA 3	2,114.36/6,936.87	2,143.52/7,032.55	29.16/95.68

Table 2b: Depth to Top and Base of Overpressure and Corresponding Thickness for EBUBU-007 Well.

	Top (m/ft)	Base (m/ft)	Thickness (m/ft)
OVA 1	1,946.67/6,386.71	1,964.90/6,446.51	18.23/59.8
OVA 2	2,110.71/6,924.91	2,136.23/7,008.63	25.52/83.72
OVA 3	2,220.08/7,283.72	2,256.53/7,403.32	36.45/119.60
OVA 4	2,606.49/8,551.49	2,650.24/8,695.01	43.74/143.52
OVA 5	2,810.64/9,221.26	2,985.62/9,795.34	178.63/586.06

Table 2c: Depth to Top and Base of Overpressure and Corresponding Thickness for ONNE-001 Well.

	Top (m/ft)	Base (m/ft)	Thickness (m/ft)
OVA 1	1,935.73/6,350.83	1,946.67/6,386.71	10.94/35.88
OVA 2	2,081.55/6,829.23	2,103.42/6,900.99	21.87/71.76
OVA 3	2,351.31/7,714.28	2,416.93/7,929.56	65.62/215.28
OVA 4	2,701.27/8,862.45	2,748.67/9,017.93	47.39/155.48
OVA 5	2,930.94/9,615.94	3,047.59/9,998.66	116.65/382.72

Table 3: Check Shot data and Calculated Interval (V_{INT}) and Average (V_{AV}) Velocities for ONNE-001 Well.

Depth (ft)	One-Way Travel-Time (sec)	Two-Way Travel-Time (sec)	V _{INT} (ft/s)	V _{AV} (ft/s)
3,417	0.525	1.050		
4,917	0.714	1.428	7,937	6,726
5,917	0.826	1.652	8,929	7,035
7,917	1.039	2.078	9,390	7,418
9,867	1.227	2.454	10,372	7,848

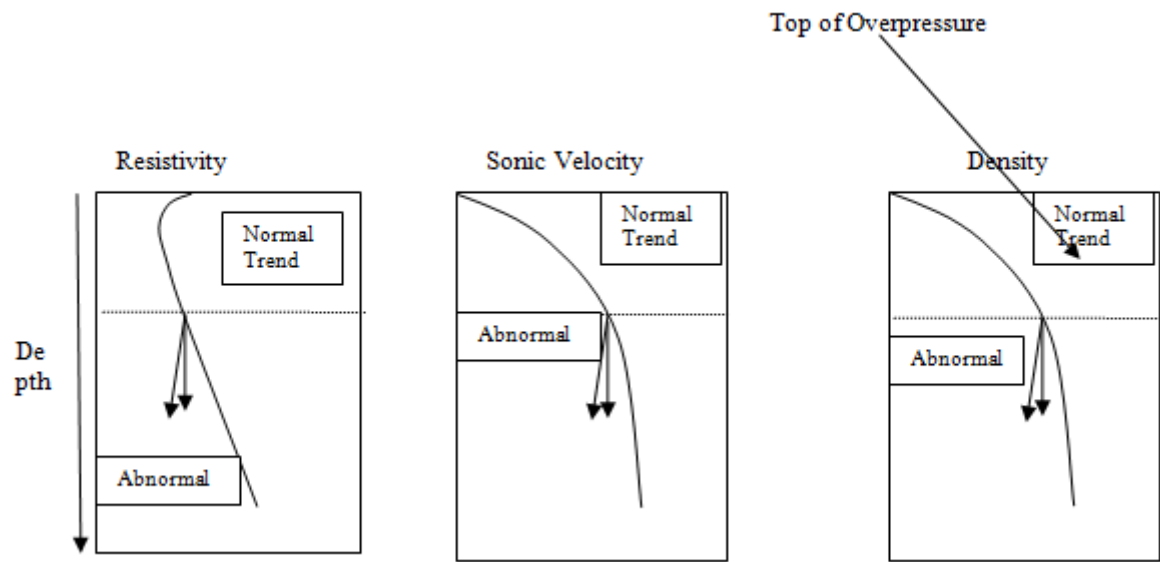


Fig 5: Wireline Overpressure Indicators. Shale resistivity, sonic velocity and density log data fall below their normal trends. Resistivity changes not related to pore pressure could be caused by variation in pore water temperature and salinity (After Bowers, 2002)

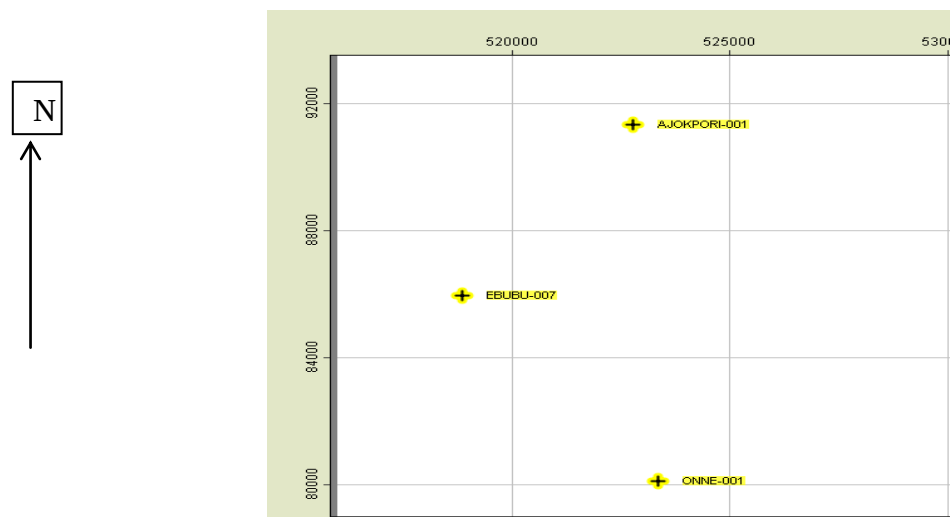


Fig 6: Base Map Showing the Location of Studied Wells
(Produced with RokDoc®5.4.4).
Petrophysical Analysis