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Reservoir Characterization from Abnormal Pressure in Parts of Eleme, Southeastern Nigeria, Using Well Log Data

Igboekwe. M. U.*
Department of Physics, Michael Okpara University of Agriculture, Umudike, Nigeria

Udoinyang, I. E.
Department of Physics, Rhema University, Aba.Nigeria

Ohaegbuchu, H. E.
Department of Physics, Michael Okpara University of Agriculture, Umudike, Nigeria

Abstract: Pressure in Geophysics is mostly explained in terms of hydrostatics. It is a three dimensional stress state in which the magnitude of stress is the same in all directions. The pressure of a fluid is said to be "abnormal pressure" if it is greater or lower than normal. Normal pressure is regarded as the rate of increase of formation density where the pore pressure remains hydrostatic. The determination of zones of abnormal pressure was done using geophysical well log method in the Eleme area. Sonic log and density log formed the porosity log and consequently the porosity data. The logs were interpreted and plotted against depth. The trends were analysed for wells and abnormal pressure. Overpressure was determined in between particular depths. For the two wells used, it is found between 2185m and 2785m for well A and 1805m to 2525m for well B. Abnormally high pressure zones have density of formation greater than 1.07kg/cm^3. They also have pressure gradients exceeding hydrostatic pressure gradients of 0.433psi/ft to 0.435psi/ft for fresh and brackish water with less than 20000ppm of salt and 0.465psi/ft for salt water with about 80000ppm salt content. The determined abnormal pressure can be taken as a guide in the Eleme area of Nigeria when oil wells are to be drilled.

Keywords: Reservoir characterization; Abnormal pressure; Eleme; Well logs.

1. Introduction

Formation pressure is the pressure experienced by fluid in the pore spaces of subsurface formations. The overburden pressure at any depth is the summation of weight of grains and the pore pressure at that depth. The pressure that the pore fluid has assuming there are no obstacles to fluid flow is known as hydrostatic pressure. Hydrostatic pressure is thus the normal pore pressure while Pore pressure is the actual fluid pressure in the sediments.

A formation is abnormally pressured when the pore fluid pressure is significantly below or above the normal hydrostatic pressure for the depth considered, Jiao and Zheng [1]. The difference between the actual pore pressure and the hydrostatic (normal) pressure at a given depth is called overpressure. Overpressure is the pressure which exceeds the pressure of a static column of water or brine, Dickinson [2]. It is the result of the inability of formation fluid to escape at a rate which maintains equilibration with a column of formation water which exists to the surface, Swarbrick and Osborne [3]. Overburden stress or lithostatic pressure is the weight of the entire overburden and it increases with depth. The net compressive stress on the rock fabric, that is, the difference between the lithostatic stress and the pore pressure is the effective stress on the formation, Yardly and Swarbrick [4].

An accurate prediction of the subsurface pore pressures is necessary requirement to safely, economically and efficiently drill the wells required to test and produced oil and natural gas reserves. Pore pressures are easily predicted for normally pressured sediments but challenging when the sediments are abnormally pressured. An understanding of the pore pressure is a requirement of the drilling plan in order to choose proper casing points and design a casing program that will allow the well to be drilled most effectively and maintain well control during drilling and completion operations. Well control events such as formation fluid kicks, lost circulation, surface blowouts and underground blowouts can be avoided with the use of accurate pore pressure and fracture gradients predictions in the design process, Fooshee [5]. Pore pressures are largely determined by analysis of relevant data, coupled with knowledge of burial, stress and temperature histories, rock types and their distributions, subsurface structure and reservoir connectivity.

Overpressure detection is based on the premise that pore pressure affects compaction dependent geophysical properties such as density, resistivity and sonic velocity. Shale is the preferred lithology for pore pressure

*Corresponding Author

interpretation because they are more responsive to overpressure than most rock types. Consequently, overpressure detection centers around shale deformation behaviour, Bowers [6].

2. Geological Setting of the Study Area

The Eleme area is in the Southeastern Nigeria. It is lying within the Niger Delta area. This region is found between the latitude of about $4^{o}6^{'}$N and $4^{o}10^{'}$N [7]. This area is made up of a sedimentary formation, the Agbada formation [8, 9].

The Agbada formation is made up primarily of alternating sandstones and shales. The sandstones are found in its upper part while the lower part has shales. It ranges in age from Eocene in its northern part to Pliocene in the south. The maximum thickness attained is about 4572m [10]. This area is found to be very important for oil explorations due to the fact that the greatest parts of hydrocarbon occurrence were found in this zone [11]. Emphasis is laid on overpressure, its causes and correlation of results obtained from interpreted well logs.

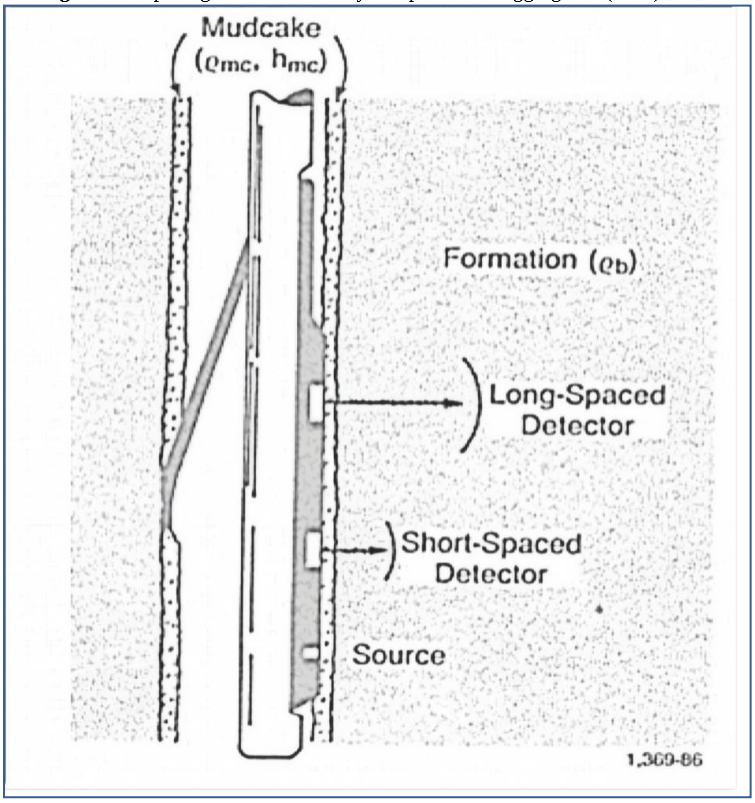
3. Study Methods

The geophysical methods employed are the well logging methods in which some formation features are measured with depth. The logging tools used for these are the dual spacing formation density compensation tool (FDC), Borehole compensation dual transmitter system (BHC). These methods involve the application of electrical, sonic, and density measurements. Resistivity and acoustic impedance are amongst the methods which can be used to deduced reasonable result. In this work, effort is made to estimate formation pore pressure, and assess mud weight requirement.

The formation density compensation is to compensate for mud cake and minor borehole irregularities. Its main principles are a radioactive source, applied to the borehole wall in a shielded side wall skid. It has two detectors, the long and the short detectors. The short detector is sensitive to the mud cake and borehole irregularities. The long spaced detector is sensitive to the formation bulk density p_b, mud cake density p_{mc} and the thickness h_{mc}.

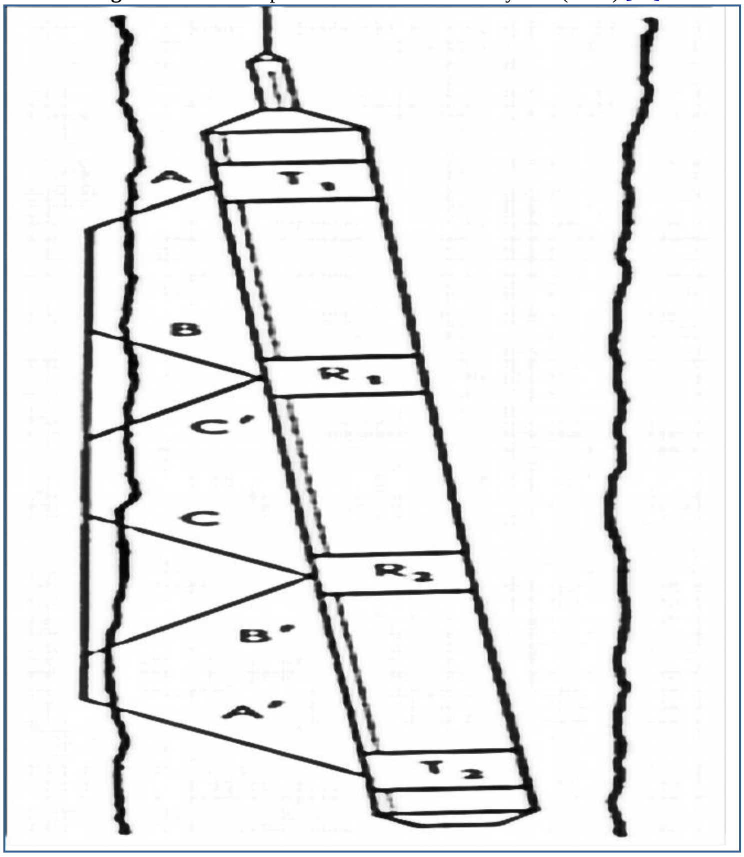
The radioactive source emits medium energy gamma rays into the formations. The gamma rays make an interaction in the form of Compton scattering. The gamma rays as they are assumed to be high velocity particles collide with the electrons in the formation. The number of electrons in the formation is related to the Compton scattering collisions. The electron density therefore becomes the essential factor in the determination of bulk density, p_b. Since the density of the fluids filling the pores, the formation porosity, the density of the rock matrix material is related to the true bulk density, the response of the tool is therefore to the density of the electron, which is the number of electrons per cubic centimetres.

Fig-1. Dual spacing formation density compensation logging tool (FDC) [12].



Borehole Compensation Dual Transmitter System (BHC) incorporates two transmitters and four receivers. It is used to compensate for sonic logs. When a sonic log is being run in the borehole there are the acoustic waves as a result of wave refraction and reflections. Sound from the transmitters impinges on the wall of the borehole, establishing surface wave, compressional and shear waves, within the formation and fluid column.

Fig-2. Borehole compensation dual transmitter system (BHC) [12].



The data used in the work is obtained at well site in the course of drilling into an oil well. The logs were collected as composite logs from two wells, well A and well B. The result was obtained by sending the tool downhole in the well borehole and the bulk density is recorded in grams/cm^3 giving us the density logs. The transit time (Δt) is recorded in microsecond per feet giving us the sonic logs. Bulk densities were picked at a regular interval of 40m per rate of penetration (m/RT). These were presented in tables. Also, the transit time (Δt) msec/ft values were picked at a regular interval of 40m/RT from the sonic logs of both wells. The values were also presented in tables.

Acoustic impedance (Z_a) is the product of compressional velocity (1/Δt) and bulk density p_b, that is, $Z_a = p_b/\Delta t$.

For the sonic log, it has a scale which is increasing from right to left and has ten (10) divisions in well B and five (5) vertical divisions in well A. Meaning that in well A, one division equals 20msec/ft and in well B one division equals 10msec/ft. The inverse of the transit time (Δt) in microsecond per metre gives the velocity.

The density logs has a scale which is increasing from left to right in well B; there are 10 vertical divisions and 5 vertical division in well A. One division equals 0.2g/cm^3 in well A and 0.1g/cm^3 in well B.

4. Field Techniques

The techniques involved in this work include the seismic investigation, D-exponent method and pore-pressure evaluation. Gas monitoring, mud temperature and salinity trend. The seismic investigation is accurate to ±500 ft with 90% reliability. It (seismic investigation) is also used to correlate well logs in developed reservoir(s), whilst the D-exponent is a number relating the rate of penetration, rotary speed, weight on bit and bit diameter.

Formation tester was used for drill stem test. Well kick data was used to investigate what fluid can be produced from a certain interval in a well. These are necessary for pore pressure evaluation. Continuous gas monitoring of flow line mud stream during drilling, and evaluation of formation water salinity would indicate abnormal pressure where carefully measured.

Another very important field technique is the appropriate use of measured parameters for the evaluation of results. For the density log, using the formula, according to John Rhea, 1994.

$$\rho_b = \frac{mass}{molar\ mass}$$

$$= \frac{Rockmass + Fluidmass}{Volume} \qquad \ldots(1)$$

Where
Rockmass, $M_{ma} = \rho_{ma}(1-\varphi)V_b$
Fluidmass, $M_f = \varphi V_b$

$$\rho_b = \frac{\rho_{ma}(1-\varphi)V_b + \rho_f \varphi V_b}{V_b}$$

$$\rho_b = \rho_{ma} - \rho_{ma}\varphi + \rho_f\varphi = \rho_{ma} - \varphi(\rho_{ma} + \rho_f) \quad ...(2)$$

Where φ is porosity, p_{ma} is matrix, p_b is formation bulk density, p_f is fluid density.
Using Wyllie time average equation, porosity determination will be made possible for use.

$$\frac{1}{V_b} = \frac{\varphi}{V_f} + \frac{1-\varphi}{V_{ma}}$$

$$\Delta t = \Delta t_f \varphi + \Delta t_{ma}(1-\varphi)$$

$$= \Delta t_f \varphi - \Delta t_{ma}\varphi + \Delta t_{ma} \quad ...(3)$$

φ = porosity, Δt = interval transit time, Δt_{ma} = transit time of matrix material, Δt_f = transit time of saturating fluid.

Similarly, evaluation of result using sonic transit time after use of seismic investigation is done using Wyllie time average equation, which is equal to

Total travel time = travel time in liquefaction + transit time in matrix friction.

Mathematically, $$\frac{1}{V_b} = \frac{\varphi}{V_f} + \frac{1-\varphi}{V_{ma}} \quad ...(4)$$

The acoustic velocity is obtained during seismic investigation by computing the inverse of the transit time Δt in microsecond per metre.

5. Result and Interpretation

Transit time, bulk density, acoustic velocity, acoustic impedance and porosity with depth of well A and well B were obtained and presented in tables. Table 1 is for well A while table 2 is for well B.

Table-1 – Well A

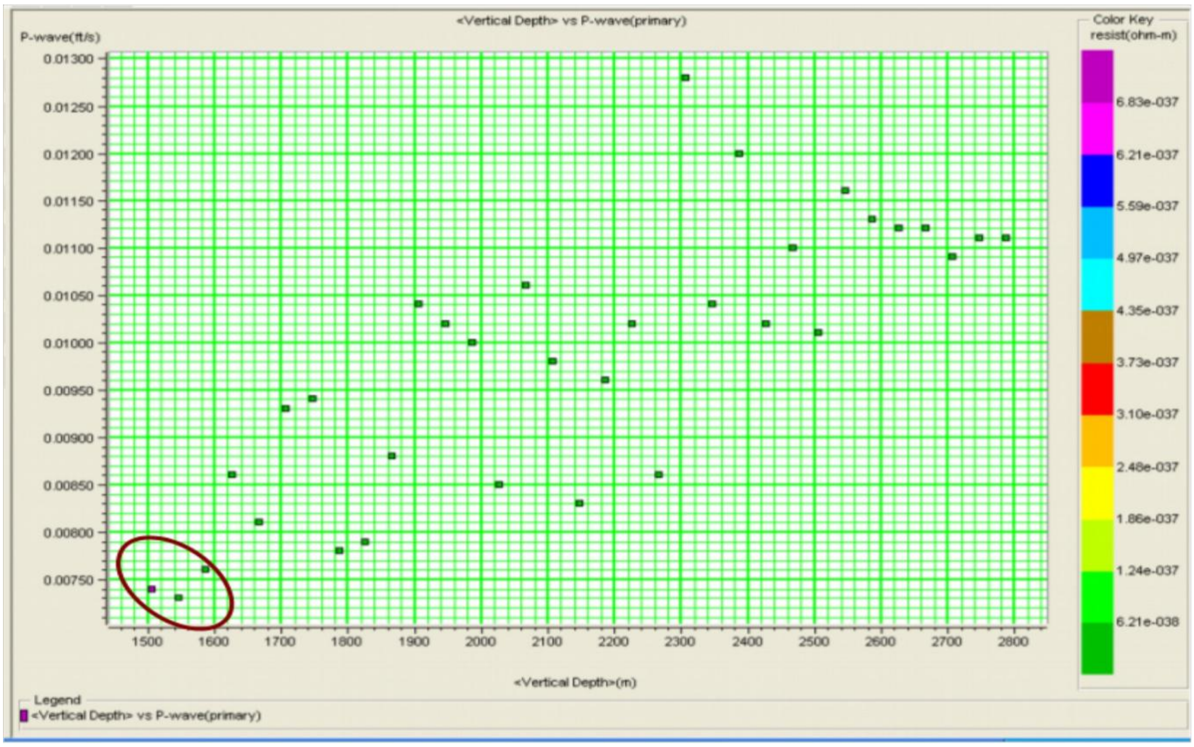
Depth (m)	Acc. Vel. (m/sec)	TT	Bulk Density	Acoustic Imp.
1505	0.0074	135.00	2.158	15.069
1545	0.0073	138.00	2.202	16.075
1585	0.0076	131.00	2.180	16.568
1625	0.0086	116.00	2.323	15.978
1665	0.0081	119.00	1.863	15.649
1705	0.0093	107.00	2.360	21.948
1745	0.0094	106.00	2.202	20.699
1785	0.0078	128.80	1.894	14.773
1865	0.0088	13.300	2.158	18.990
1905	0.0104	96.000	2.356	24.502
1945	0.0102	98.000	2.268	23.470
1985	0.0100	100.00	2.301	23.010
2025	0.0085	118.00	1.882	15.997
2065	0.0106	94.400	2.224	23.574
2105	0.0098	102.40	2.158	21.148
2145	0.0083	120.00	2.400	19.920
2185	0.0096	104.00	2.202	21.139
2225	0.0102	98.000	2.378	24.256
2265	0.0086	116.00	2.268	19.505
2305	0.0128	78.000	2.224	28.467
2345	0.0104	96.000	2.169	22.558
2385	0.0120	91.100	2.224	26.668
2425	0.0102	98.000	2.378	24.256
2465	0.0110	91.100	2.202	24.222
2505	0.0101	98.000	2.378	24.256
2545	0.0116	86.000	2.206	25.590
2585	0.0113	88.400	2.202	24.662
2625	0.0112	88.900	2.202	24.662
2665	0.0112	88.900	2.422	27.126
2705	0.0109	91.500	2.268	24.721
2745	0.0111	90.000	2.468	27.395
2785	0.0111	90.000	2.272	25.219

Transit time, bulk density, acoustic velocity, acoustic impedance and porosity with depth of well A and well B were obtained and presented in tables. Table 1 is for well A while table 2 is for well B.

Table-2 – Well B

Depth (m)	Acous. Imp.	Bulk Density	Acous. Vel.	Trans. Time
1605	21.17	2.326	0.0091	109.70
1645	16.98	2.234	0.0076	131.70
1685	16.31	2.234	0.0088	113.30
1725	20.31	2.284	0.0083	120.00
1765	19.37	2.234	0.0083	120.00
1805	17.82	2.284	0.0078	128.30
1845	19.51	2.351	0.0083	120.00
1885	19.51	2.284	0.0085	117.00
1925	20.30	2.388	0.0085	118.30
1965	20.78	2.284	0.0091	110.00
2005	21.84	2.184	0.0100	99.700
2045	23.34	2.334	0.0100	99.200
2085	00000	00000	0.0095	105.00
2125	00000	00000	0.0101	99.400
2165	00000	00000	0.0095	105.00
2205	00000	00000	0.0102	98.300
2245	00000	00000	0.0097	103.00
2285	00000	00000	0.0091	110.00
2325	00000	00000	0.0102	98.000
2365	00000	00000	0.0103	97.000
2405	00000	00000	0.0109	91.700
2445	00000	00000	0.0102	83.300
2485	00000	00000	0.0101	99.300
2525	00000	00000	0.0118	85.000

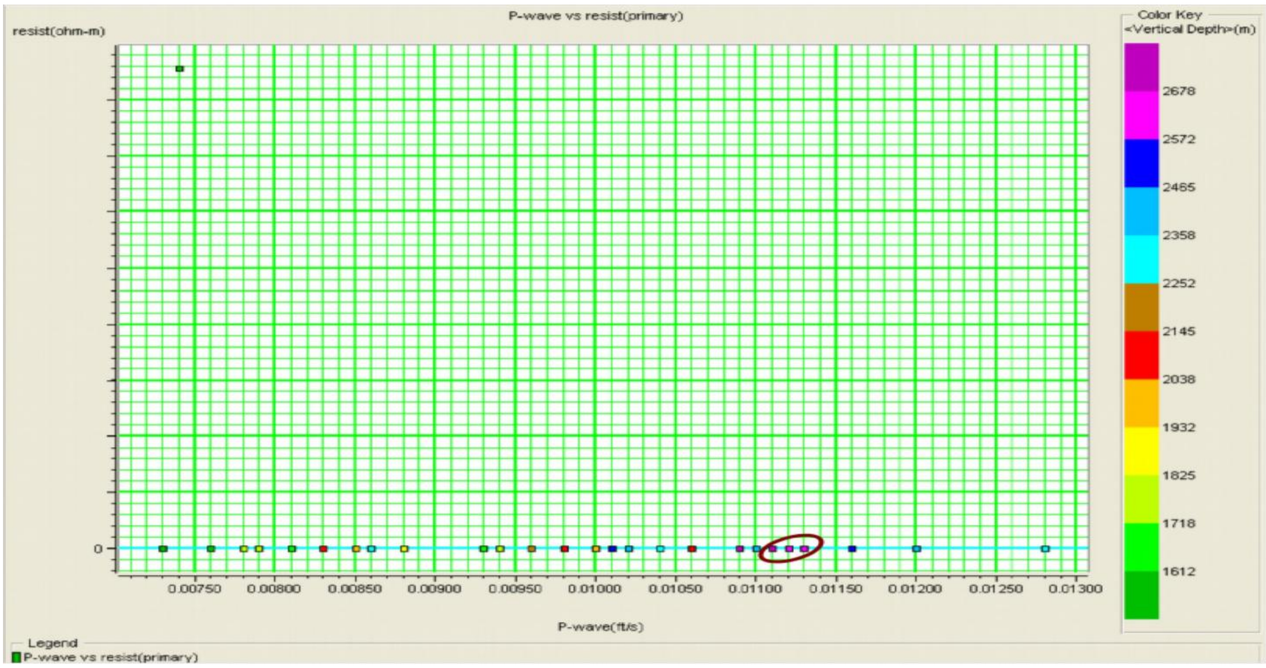
Fig-3. Resistivity vs P-wave velocity



At maximum depth, we have lower P-wave velocity. At same point, we have low resistivity meaning that the anomaly cannot be hydrocarbon accumulation but probably fracture.

Fig-4a. P-wave velocity against vertical depth (with resistivity as colour code).

Anomaly is found between 2572m and 2784m where there is decrease in P-wave velocity whereas it should



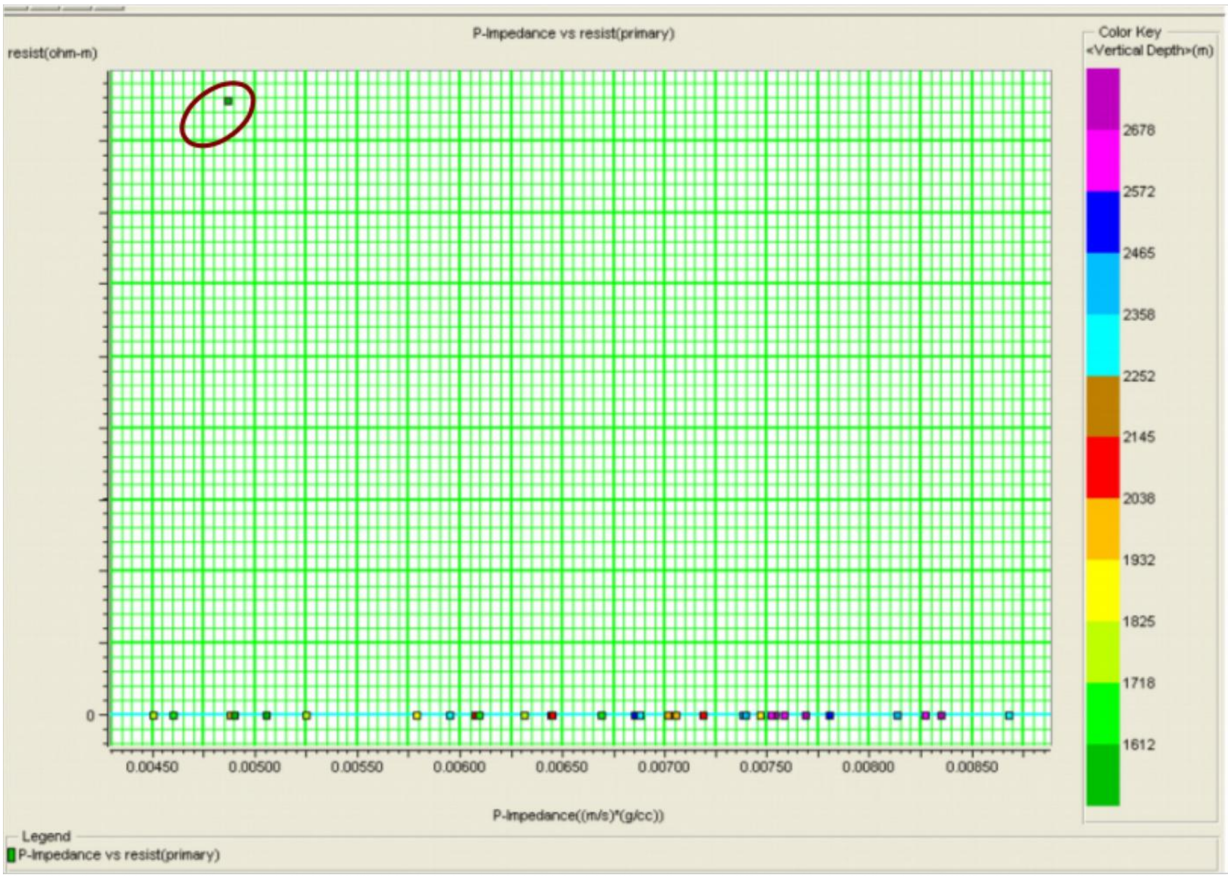
increase. There is low resistivity at this depth.

Inference: There is possibility of that the anomaly is caused by gas based on the low resistivity value. The only inference we are left with is fractures.

Fig-4b. P-impedance vs Density (with vertical depth as colour code).

There is very low P-impedance and low density at shallow depths 1612 - 2038m. This signifies the presence of hydrocarbons. However, at maximum depth range 2572 – 2784m, we see lower P-impedance and lower densities which are an anomaly. Inference: gas or fractures.

Fig-5. Resistivity vs P-impedance.



Only one point "P" shows high resistivity while other points are low resistivities. High resistivities are usually associated with hydrocarbons. The sampling frequency is too large; 40Hz/sample. This means that the only point "P" cannot be ignored.

Inference: At maximum depths of 2572 – 2584m, the P-impedance is low with low resistivity. If there were gas condensate, the resistivity would be high. Therefore, the possibility of gas as a cause of the low impedance is out and the only option left is fractures.

Interpretation on sonic log showed the transit time graph as one that decreased with depth up to a depth of about 2425m for well A. There is a steady increase of Δt at the depth of about 2465m to a depth of 2785m, showing a range of depth of abnormal pressure. For the acoustic velocity, there is excessive pressure at the depth of 2465m to 2985m for well A. Assessment showed that a range of excessive pressure exists from 2205m to about 2285m for well B. Acoustic impedance gave the depth of this pressure at about 2425m down the bore. Also the depth of 1725m holds abnormal pressure level for well B. For bulk density, plotted graph of data against depth indicate that there is a decrease of (bulk density) at a depth of about 2265m down the hole.

6. Discussion and Conclusions

The determination of the extent of abnormal pressure is important to proper well planning. It is also necessary for safety drilling practices. On the average, the depth of 2275m was found to be the depth of abnormal pressure in Eleme area.

The distribution of abnormal pressure in the Eleme area shows well defined trends with depth of over pressured zone from 1828m to the depth of 3965m.

Most of the abnormal pressured zones in the southeastern Nigeria especially in the Eleme area is in the Agbada formation. Within the limit of errors, the values are approximate estimates as determined overpressure zones sometimes are not easily quantified. This is as a result of cost. Also reasons not far from the dynamics of the earth that may affect depth of overpressure from time to time.

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