

Predicting overpressures and saturating fluids in Niger delta formations using Poisson's ratio-diagnostic chart approach

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ABSTRACT

The focus in this research is based on the Poisson's ratio and p-impedance plots of the suspect overpressure zones on a diagnostic chart developed to aid in pore pressure and saturating fluid confirmations within Niger Delta. Three points were used in the study involving wells PSW₁ and PNW₂ located within Port Harcourt Nigeria; at 67km S33.2°W and 113.6km N9.4°W respectively. While six points were used in the case of WSW₃ located within Warri Nigeria at about 115.1km and S81.2°W where no prior confirmation existed or possibly the depth range of suspicion of overpressure was large. The saturating fluids were also revealed based on their locations on the diagnostic chart.

Keywords: CMP gathers, P-impedance, Poisson's ratio, S-impedance, Shear-wave.

1. INTRODUCTION

[1] was probably first to record the decrease of PR with decreasing differential pressure in room-dry granite and dolomite samples. [2] also presented this effect and proposed the use of Poisson's ratio to identify saturating fluids. [3] stated that the Vp/Vs ratio in gas-saturated rocks increases with increasing differential pressure while [4] supports this statement by laboratory velocity measurements in carbonate samples. Pore fluid does not support shear-wave propagation, and poor grain-to-grain contacts in the overpressured zones with low effective stress affect the S-velocity even more than the P-velocity. This has been observed in the laboratory [5] and modeled [6]; [7]; [8]. The Vp/Vs ratio (which is directly related to Poisson's ratio) is a key parameter that relates to low effective pressure or high pore pressure, especially in pore pressure close to fracture pressure condition. This has not received much consideration in pore pressure prediction methodologies, mainly because the traditional seismic approach for pressure prediction used the conventional P-velocity data only.

The increase of saturated-rock PR with increasing pore pressure has physical basis. The higher the pore pressure, the softer the rock and the larger the relative increase in the bulk modulus between dry and water-saturated samples. With the shear modulus being the same for the dry and saturated rock [9], PR is larger in saturated than in dry sample, especially in soft rocks. The difference in the dry and saturated PR versus effective stress suggests a very different seismic signature for the two cases in the amplitude-versus-offset (AVO) domain. Modern pore pressure prediction methods exploit this fact by inverting CMP gathers using the full waveform inversion technology that allows extraction of the Vp/Vs ratio from large offset P-wave data [10]; [11]. [12] demonstrated how to use this effect on shear velocities that were determined from mode converted wave reflections for subsalt pore pressure prediction.

P-wave impedance and Poisson's ratio can be obtained from seismic data using acoustic and elastic impedance inversion (e.g., [13]). It is, therefore, important to create diagnostic rock physics based charts that will help interpret the inversion results in terms of pore pressure and pore fluid. An example of diagnostic charts is given in Figure 1, based on laboratory measurements of the elastic-wave velocity in unconsolidated North Sea sands [14]. This has been found to match favourably (on minor adjustments) with Niger Delta sands [15]. Different regions in the PR versus P-wave impedance plane and P-impedance versus S-impedance plane correspond to different pore pressure and pore fluid. One can identify both pore pressure and pore fluid from seismic (and separate the pore pressure effect from the pore fluid effect) by superimposing seismic elastic rock properties on a diagnostic chart. Such plots, calibrated to specific locations and lithologies of interest, can guide us in looking for anomalies in seismic attributes that might indicate overpressures. The arrows indicate the direction of pore pressure increase while the overpressured zones are differently coloured.

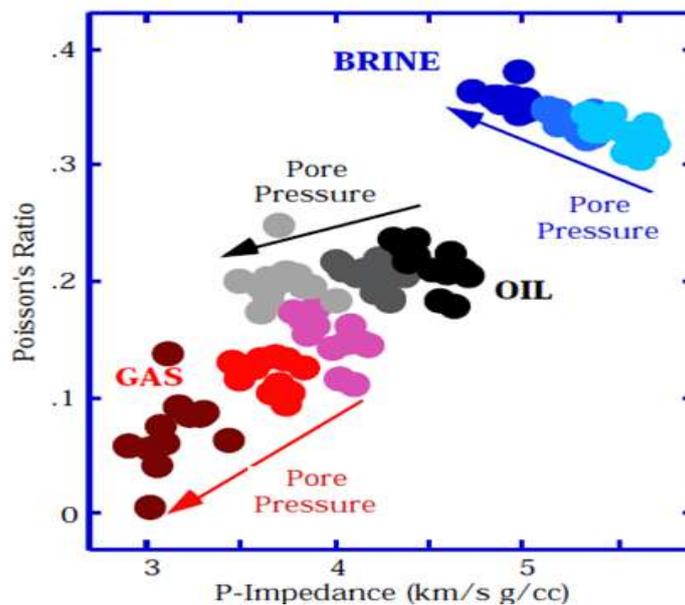


Figure 1: Pore pressure and pore fluid diagnostic chart [15]

[16] has shown that for unconsolidated sediments, very low effective pressures can be detected by changes in V_p/V_s ratios and by changes in P- and S-wave amplitude and frequency content. At very low pressures, both P- and S-wave amplitudes change drastically. However, for a pressure change of about 1 MPa, the frequency content of the P-waves changes only by about 8%; the corresponding change for S-waves is over 150%.

2. BRIEF GEOLOGY OF STUDY AREA

The Niger Delta Basin occupies the Gulf of Guinea continental margin in equatorial West Africa, between latitudes 3° and 6°N and longitudes 5° and 8°E (with greater portion laying within Nigerian inland). It ranks among the world's most prolific petroleum-producing Tertiary deltas, and has been rated sixth largest oil producer and twelfth hydrocarbon province occupying about 100,000 sq.mile [17]. As a sedimentary basin, the Niger Delta encompasses a region that is much larger than the geographical extent of the modern delta constructed by the Niger-Benue drainage systems. It embraces other deltas "which are not members of the Niger system" [18], notably the Cross River Delta [19], and extends into the continental margins of neighbouring Cameroon and Equatorial Guinea, which therefore "have portions of the Niger Delta that contain hydrocarbons" [20]. The base of the Delta consists of massive and monotonous marine shales (Akata formation) which grade upwards into interbedded shallow-marine and fluvial sands, silts and clays (Agbada formation) that form the typical paralic facies portion of the delta. The uppermost part of the Delta sequence is a massive nonmarine sand section known as Benin formation [21].

The Niger Delta Basin holds enormous petroleum reserves, estimated at about 30 billion barrels of oil and 260 trillion cubic feet of natural gas, ranking the delta seventh in world production, with a current average production of about 1.8 million bbl of oil/day. A few giant oil and condensate fields, with reserves exceeding 500 million bbl occur in the Niger Delta [22]. The basement map of Niger Delta is shown in figure 2, bearing the study wells in blue.

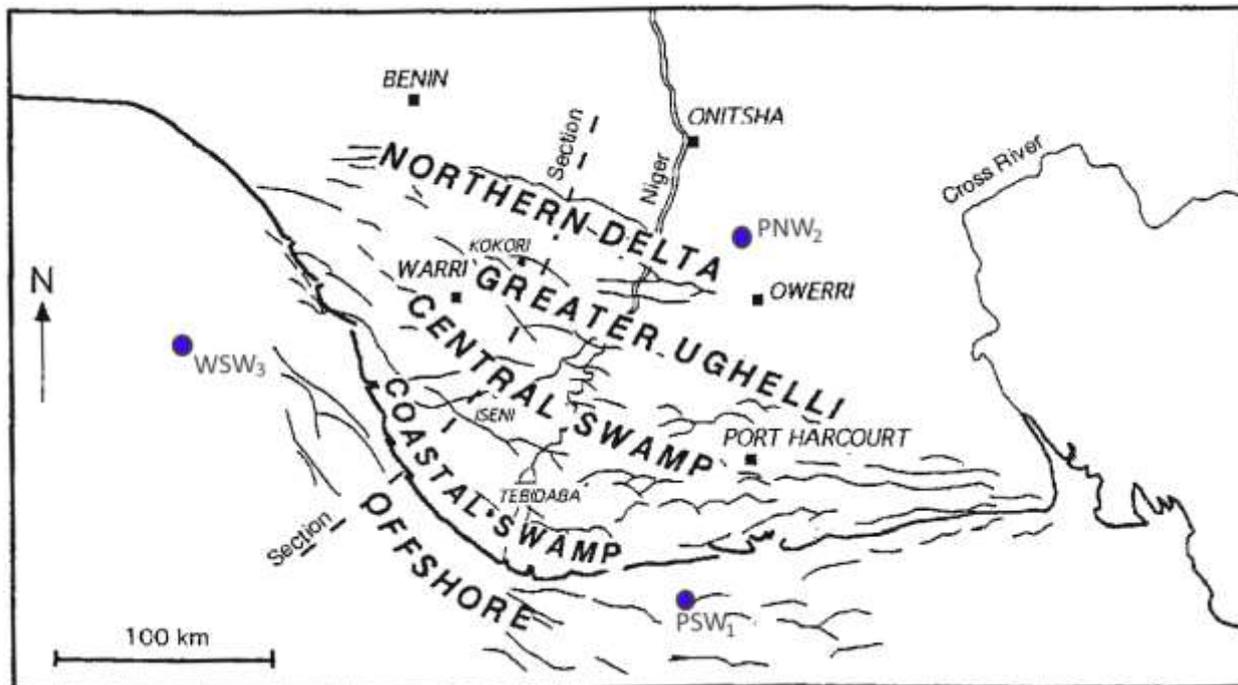


Figure 2: Map of Niger Delta showing the locations of the study wells

3. THEORETICAL BACKGROUND AND METHODOLOGY

In this process, I computed density (ρ) from Gardner's rule [23] given by;

$$\rho = av^{\frac{1}{4}} \quad (1)$$

where ρ is in g/cm^3 , "a" has the value of 0.31 and "v" is the P-wave interval velocity in m/s. When v is expressed in ft/s, then "a" would have the value of 0.23. (1) is usually used for shale, sandstone, dolomite, and limestone because of their relatively narrow swath across the graph (that is they are close to the dotted diagonal line derived from (1)) – see fig. 3. One can as well use this chart in fig. 3 to estimate density for a given formation when the velocity is known; this is usually the case for coal, salt, and anhydrite that are widely separated from the diagonal dotted lines.

The product of velocity and density for a given formation yields the P-wave impedance for that formation; while Poisson's ratio was computed from (2).

$$P.R = \frac{0.5 \left(\frac{v_p^2}{v_s^2} - 2 \right)}{\left(\frac{v_p^2}{v_s^2} - 1 \right)} \quad (2)$$

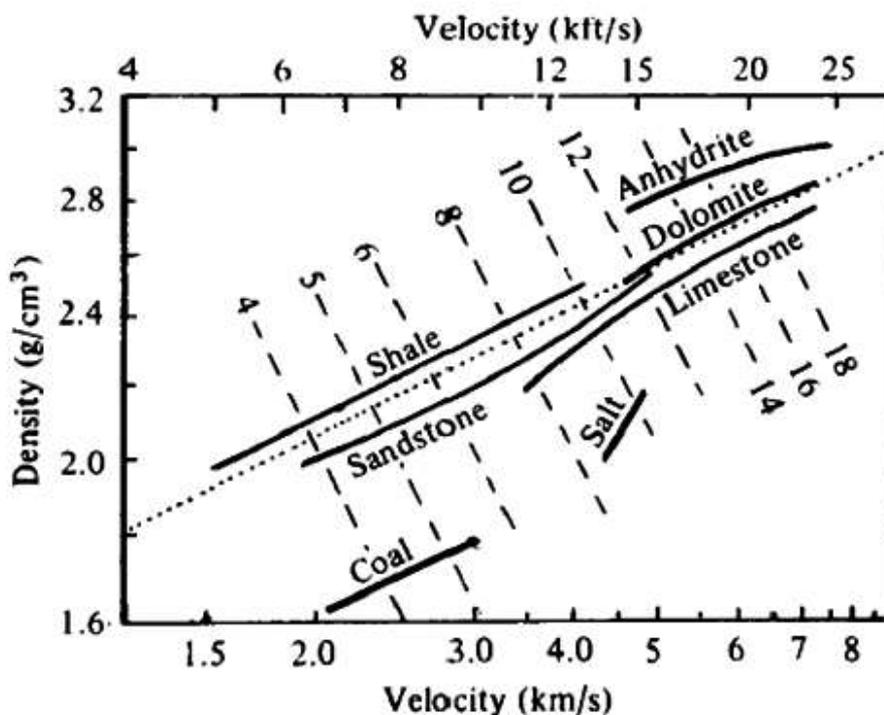


Figure 3: P-wave velocity-density relationship for different lithologies on log-log scale. [23]

I then selected at least three points from the depth of investigation on the v_p and v_s sections and converted their velocities to km/s. Next I used (3) [24];

$$\rho(\text{g/cm}^3) = \sqrt[4]{9.23521 v_p} \quad (3)$$

which is generated from (1) to compute the density. After this, I computed the P-impedance by multiplying the V_p and the ρ . The final computation involved generating the $\frac{v_p}{v_s}$ which in turns yielded the Poisson's ratio with the aid of (2). A table would be generated for the p-impedances and their corresponding Poisson's ratios for the various points of interest to be plotted on the chart of fig. 1; this will in turn be used to predict pore fluid and overpressures.

4. DATA PRESENTATIONS AND ANALYSES

The data presentations and analyses for the three Niger Delta wells studied are given as follows;

PSW₁ Well data and analysis

Table1: Diagnostic Chart Data for PSW₁

	Vp(km/s)	Vs(km/s)	$\rho(\text{g/cm}^3)$	P-imp	$\frac{V_p}{V_s}$	$\left(\frac{V_p}{V_s}\right)^2$	P.R
Point 1	1.751	1.061	2.005	3.51	1.65	2.72	0.21
Point 2	1.802	1.110	2.020	3.64	1.62	2.62	0.19
Point 3	1.810	1.070	2.022	3.66	1.69	2.86	0.23

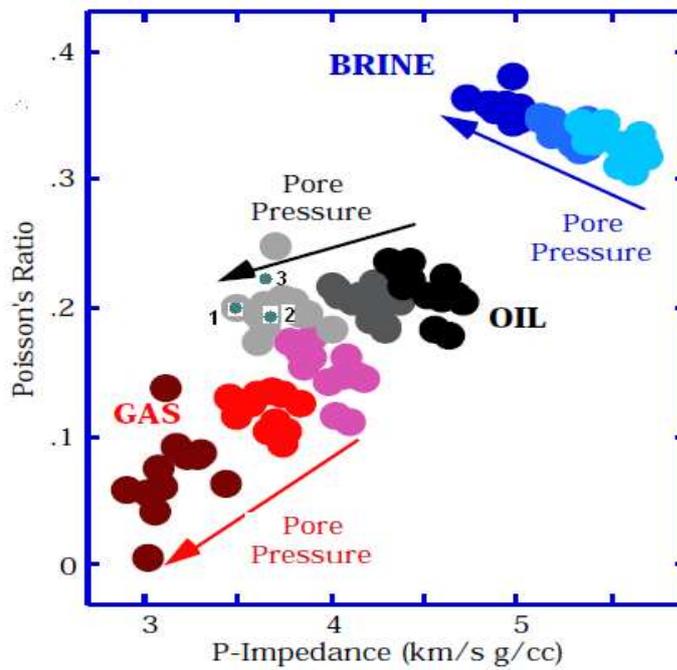


Figure.4: Diagnostic chart plot for PSW₁

4.1 PNW₂ Well data and analysis

Table 2: Diagnostic Chart Data for PNW₂

	Vp(km/s)	Vs(km/s)	ℓ(g/cm ³)	P-imp	$\frac{Vp}{Vs}$	$\left(\frac{Vp}{Vs}\right)^2$	P.R
Point 1	1.857	1.248	2.035	3.78	1.488	2.214	0.088
Point 2	1.798	1.173	2.019	3.63	1.533	2.351	0.130
Point 3	1.900	1.241	2.047	3.89	1.531	2.344	0.128

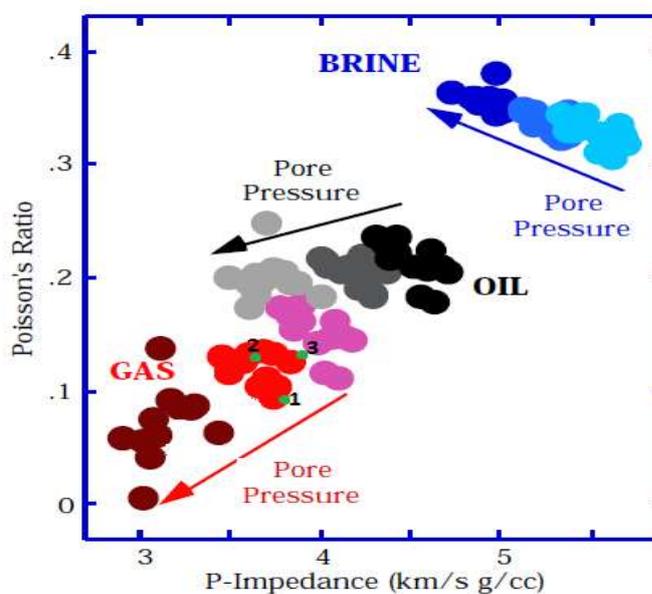


Fig. 5: Diagnostic chart plot for PNW₂

4.2 WSW₃ Well data and analysis

Table 3: Diagnostic Chart Data for WSW₃

Range		Vp(km/s)	Vs(km/s)	ρ (g/cm ³)	P-imp	$\frac{Vp}{Vs}$	$\left(\frac{Vp}{Vs}\right)^2$	P.R
10,000ft	Pt 1	2.489	1.304	2.190	5.45	1.91	3.65	0.31
	Pt 2	2.435	1.179	2.177	5.30	2.07	4.29	0.35
11,000ft	Pt 3	1.511	1.036	1.933	2.92	1.46	2.13	0.06
	Pt4	1.617	1.083	1.966	3.18	1.49	2.23	0.09
12,000ft	Pt5	1.634	1.129	1.971	3.22	1.45	2.09	0.04
	Pt6	1.896	1.129	2.046	3.88	1.68	2.82	0.23

5. DISCUSSION AND CONCLUSION

Figure 4 (for PSW₁) is a clear case of overpressured oil bearing formations for points 1, 2, and 3 selected. Figure 5 (for PNW₂) shows the presence of gas in points 1, 2, and 3 but not overpressured. This method has thus predicted the saturating fluid as well as fluid pressure. Three points were selected owing to the fact that this diagnostic approach is used to confirm the presence of overpressure and possibly give more ideas on the saturating fluid after using some other methods to speculate the presence of overpressures. PSW₁ is located at about 67km S33.2°W of Port Harcourt Nigeria while PNW₂ is located at approximately 113.6km N9.4°W of Port Harcourt Nigeria.

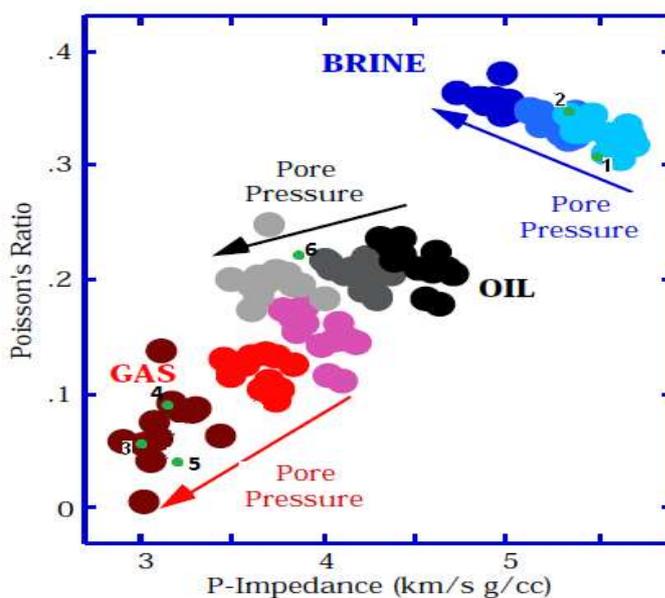


Fig. 6: Diagnostic chart plot for WSW₃

Well WSW₃ reveals a method usually adopted when no first hand speculation of overpressure exists or when the depth of guess is so wide; here I have tracked the presence of overpressure to a depth range of 10,000ft to 12,000ft and so I selected two points from each depth range as displayed in table 3. After the plots I verified that points 3, 4, and 5 were overpressured gas bearing formations; points 2 and 1 were water bearing, while points 6 could be overpressured oil formation. WSW₃ Well is located at approximately 115.1km S 81.2°W of Warri Nigeria.

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