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Hydrocarbon Productivity Studies Using Rock Properties and Attributes; A Case Study of Niger Delta, Nigeria

Ogbonna-Orji, O C.[1]; Acra, E.J[2]; Adiela, U.P[3]
[1, 2]Centre of Petroleum Geosciences, University of Port Harcourt, Nigeria
[2] Department of Geology, University of Port Harcourt, Nigeria
[3]Department of Petroleum Engineering, Nigerian Agip Oil Company, Port Harcourt, Nigeria

Abstract— *This study was carried out to evaluate time-lapse (4D) production of hydrocarbon using some rock properties and attributes from available well logs and seismic data in a Niger Delta field. Various cross-plots were initially performed where results showed that P-impedance, lambda- rho density, poison's ratio and mu-rho attributes were more robust in terms of fluid and lithology discrimination as they exhibit high sensitivity to fluids within the reservoir while Vp/Vs ratio was poor attribute in fluid discrimination. Gassmann's fluid substitution analysis also showed that density, lambda-rho and P-impedance were more sensitive to oil and gas saturations.*

I. INTRODUCTION

In recent times, there has been a growing need to understand as well as evaluate fluid movement, pressure and temperature changes as hydrocarbon is produced in any field in the oil and industry. This has made the acquisition of 4D seismic important. In this study, time-lapse evaluation of hydrocarbon production using rock properties and attributes obtained from well and 4D seismic data comprising of two 3D seismic volumes acquired at different times, has been successfully applied in an offshore Niger Delta field.

Significance of the Study

In this study, evaluation of the response of rock properties and attributes were carried out with regard to hydrocarbon production using cross-plots to;

- Understand how rock properties and attributes are related,
- Understand the importance of time-lapse seismic in reservoir monitoring.
- Determine the sensitivity of various attributes to fluid effects
- Contribute to interpretation of attribute sections; that is, which attributes are best for describing a given reservoir, and
- Serve as an effective tool for prospect definition in terms of oil recovery.

Location of the Study Area

The data-sets used for the study were acquired from an offshore Niger Delta oilfield, South —South Nigeria (figure 1). The Niger delta is situated on the continental margin of the Gulf of Guinea in Equatorial West Africa, at the Southern flank of Nigeria bordering the Atlantic Ocean between latitude3°N and 6°N, and longitude 5°E and 8°E

The structure of the field is a complex collapsed crest, rollover anticline, elongated in the E-W direction. This field has a large STOIIP with an ultimate recovery of about 50%, thus leaving huge opportunity that technology such as time-lapse seismic and smart wells can impact. The information about the time when the base survey and the monitor survey was acquired is not certain. Stacked pay sand interval of the D2000 formation is the main hydrocarbon interval as covered by the 3D data with significant amount still left.

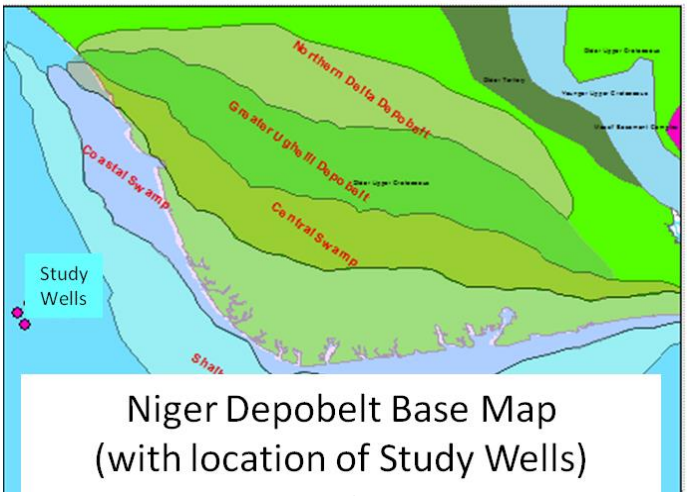

Fig. 1. Location of the study area.

II. MATERIALS AND METHODOLOGY

The impact of hydrocarbon production on rock properties and attributes was quantitatively evaluated using available data and tools in the mold of software. Two sets of 3D seismic volumes (Base and Monitor), well logs and checkshot data was serve as input for analysis. Interpretation, conclusions and recommendation, will be based on results obtained after analysis. Thus, this research was revolved around.

i. Import, edit and correct well logs using rock physics models in order to remove high frequency components,
ii. Extract wavelet for correlation and perform well to seismic tie,
iii. Cross-plot various rock properties and attributes with colour codes to validate their lithology, fluid sensitivity and discrimination capabilities,
iv. Perform fluid substitution,

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v. Run Acoustic Impedance Inversion on both base and monitor (time-lapse) seismic volume and

vi. Analyze rock properties and attribute response to fluid changes and replacement.

TABLE 1. Reservior D2000 Information across wells.

WELL NAME	MARKER	TOP (ft)	BASE (ft)	OIL DOWN (ft)	HCWC (ft)	AVE POROSITY (%)	WATER SATURATION (%)
Well A	D2000	5831	5940	-	-	28	13
Well B	D2000	5830	5966	-	-	28	9
Well C	D2000	5983	-	5983	5983	32	15

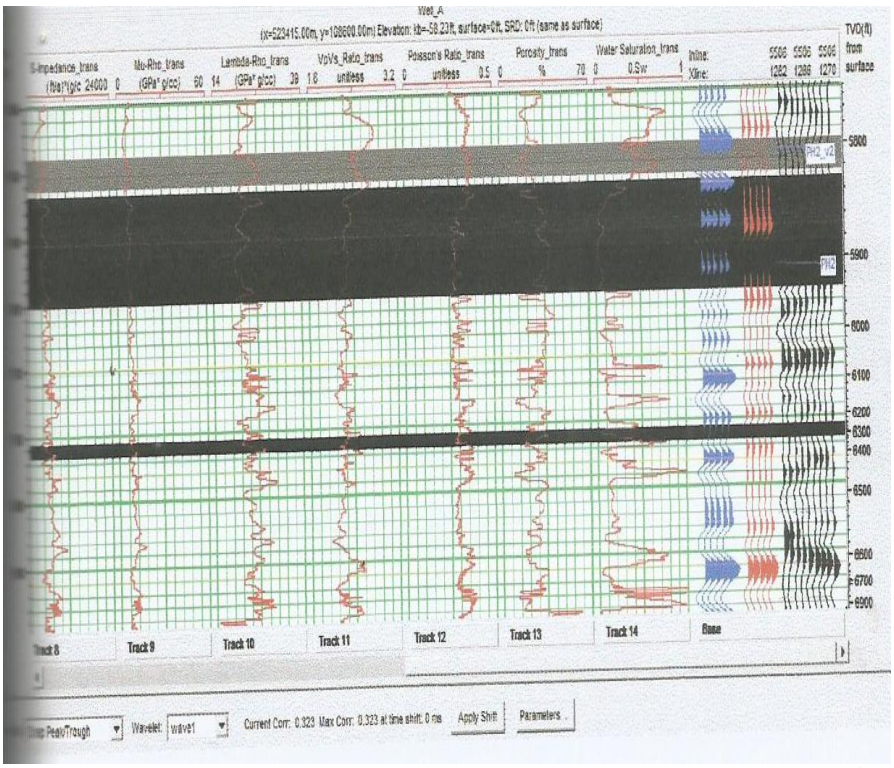

Fig. 2. Well to Seismic tie using the Base seismic data and well A log data, giving a correlation value of 0.323.

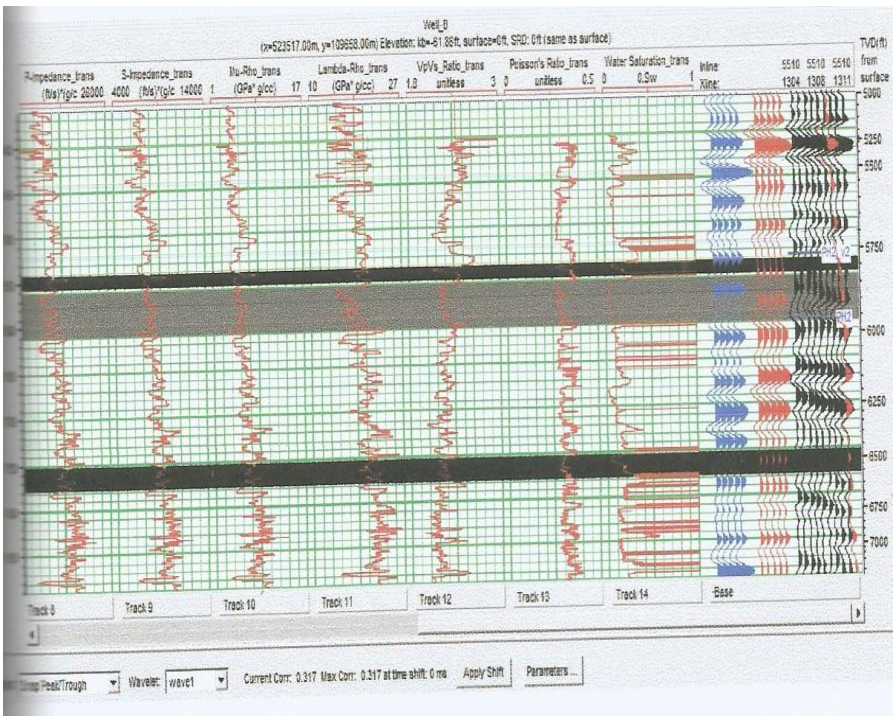

Fig. 3. Well to Seismic tie using the Base seismic data and well B log data,giving a correlation value of 0.317 at a time shift of 0ms.

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Well-To-Seismic Correllation

Well log editing for the purpose of well to seismic correlation, when done properly, often lead to excellent synthetic seismograms and well to seismic correlation (Box et. al., 2004). Log correlation entails aligning the synthetic calculated from the well logs with one or more seismic traces near the well location, thereby creating a tie between events on the synthetic traces and of the seismic. It is essential that correlation of well logs to seismic data be done as it enables the interpreter constrain his zone of interest.

In the Hampson-Russell software, the correlation of this type is done using E-log program in the suite with a composite trace. The composite trace is a single average trace, which is an average of adjacent traces around the borehole. For the seismic, the value of +1/-1 was used in averaging in inline and crossline of the borehole, which is 9 traces. This is done by convolving the reflectivity and extracted wavelet at the well location to generate the synthetic traces (blue colour). Then each peak from the synthetic trace was correlated to each peak from the real seismic trace (red colour). Log correlation can also be thought of as a type of checkshot where the depth-time pairs are provided manually by selecting points on the synthetic and tying them with corresponding points on the composite trace. The results of the correlation showed good ties between the well logs and the seismic data, considering the alignment of the events on the well synthetic trace and the field acquired seismic trace. The correlation for wells A and B can be seen in figures 2 and 3, where a correlation value of 10 and 0.329 at 0ms was gotten for wells A and B respectively.

Wavelet Estimation

The process of wavelet analysis involves the estimation of a filter that best fits well log section coefficients to the input seismic data at the well location. The wavelet extraction proess involves the use of well log and seismic data. To carry out a good well to seismic wavelet extraction was performed. This is to ensure that a wavelet which is zero-phase with the ne amplitude spectrum with that of the seismic data is used. Just as an iterative process that iiiiproved synthetic tie was performed, wavelet extraction also improved. Two wavelet tractions were performed, which were the statistical and well-based wavelet. The statistical velet is obtained from the seismic data while the well based wavelet is obtained from the well data, which represents the average of the wavelets at individual well control points. This gives approximate values of the true amplitude and phase spectra of the source wavelet, unlike that generated through autocorrelation from the seismic, as it gives only the amplitude spectrum without the phase information. A zero/constant phased wavelet was assumed during the correlation since wavelets have amplitude and phase spectra. It should be noted that the statistical wavelet extraction was followed by the well-based wavelet extraction as shown in figures 4 and 5.

Acoustic Impedance Versus Lambda-Rho Crossplot

P-impedance cross-plotted with Lambda-rho delineated three anomalous zones which can be erpreted as hydrocarbon(red), brine(blue) and shale(green) according to their pattern of usters, with density and resistivity used as colour codes. Low values of lambda-rho and Ppedance were identified which indicates hydrocarbon and complemented by low density and gh resistivity. The brine sands are characterized by high density and low resistivity while the le zones were marked by very low resistivity. However, a better discrimination is observed ong the lambda-rho axis which implies good sensitivity in terms of fluid discrimination figure 4).

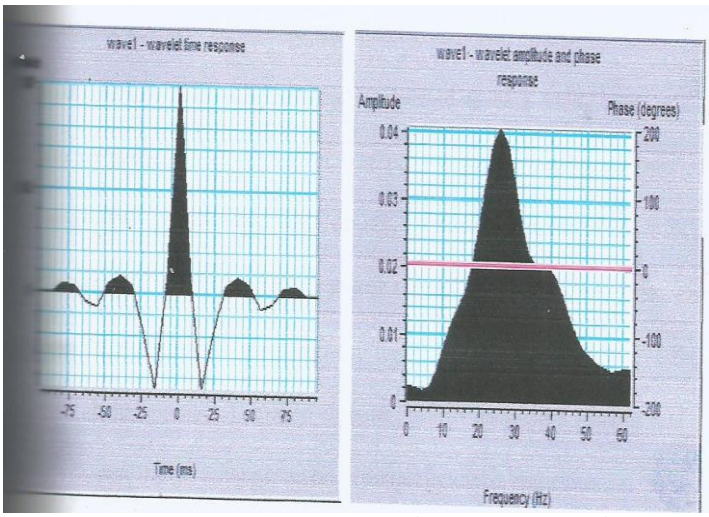

Fig. 4. Statistical zero-phase wavelt obtained from the seismic data for the purpose of correlation displayed in time and frequency domain.

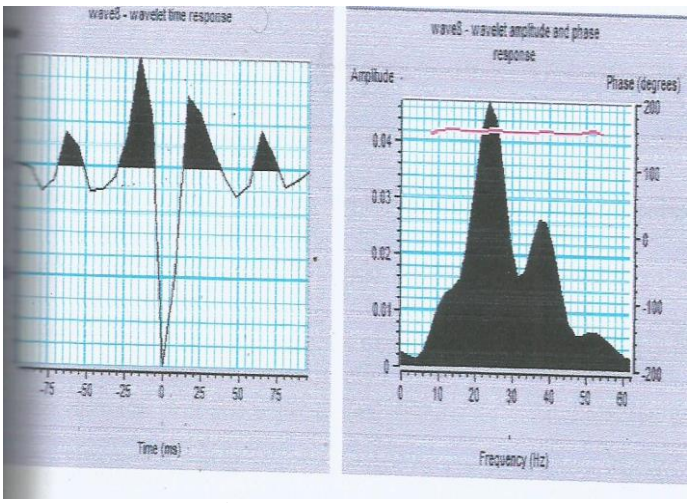

Fig. 5. Wavelet obtained from the well log data used well to seismic displayed in time and frequency domain.

Density Versus Lambda-Rho Crossplot

The cross-plot of density versus lambda-rho using resistivity and gamma ray as colour codes napped three anomalous zones (figure 6). These zones can be interpreted as probable car carbon charged, brine charged and shale zones having low values off lambda-rho corresponding to high values of resistivity. The gamma ray colour code also validated this ration. Thus, both density and lambda-rho are robust discriminators of fluid and lithology

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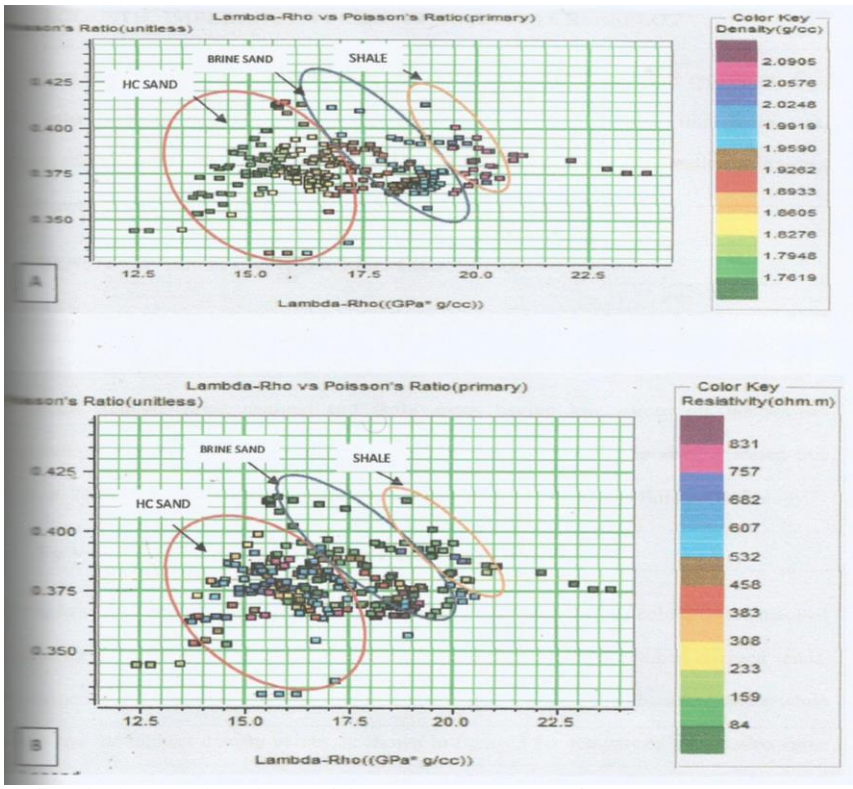

Fig. 6. Cross-plots of Poisson's ratio against Lambda-rho, with colour codes of (a) density and (b) resistivity respectively.

Vp/Vs Ratio versus Lambda-Rho Crossplot

Vs ratio versus lambda-rho cross-plot using density and resistivity as colour codes mapped three distinct anomalous zones. These zones can be interpreted as hydrocarbon charged sands, brine charged and shale zones. Low density values are observed in the hydrocarbon zones while the shale has the highest density values as shown in figure 8. Resistivity values also agree with theoretical values.

Gassmann's Fluid Substitution

Gassmann's (1951) equation was used for fluid sensitivity analysis by calculating the effect of fluid substitution on well log properties using the matrix properties. It predicts the bulk modulus of a fluid-saturated porous medium using the known bulk moduli of the solid matrix, the frame and the pore fluid. The fluid substitution model utilized production data such as pressure, temperature, gas to oil ratio (GOR), salinity and density as shown in table 2. The modeling began with 100% brine saturation and was later reduced at a rate of 25% while the oil and gas saturations were increased by the rates of 25% to 100%

TABLE 2. Production data and fluid properties for D2000 reservoir in Well B.

1960 OWC	5900ft
1990 OWC	5863ft
200 OWC	5856ft
Pressure	2532psi
Temperature	137^0F
GOR	298scf/stb
API	25API
Salinity	15000ppm

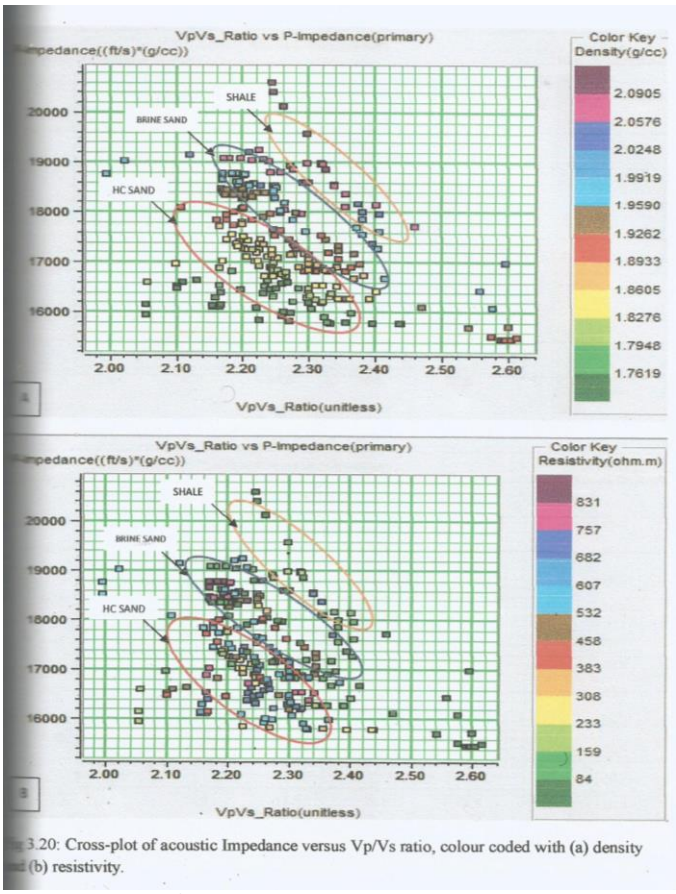

Fig. 7. Cross-plot of acoustic Impedance versus vp vs ratio colour coded with (a) density and (b) resistivity.

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Post-Stack Acoustic Impedance Inversion

Seismic inversion is the process of deriving a consistent and ideal model of the Earth's subsurface from the field seismic data for the purpose of mapping the physical characteristics of rocks and fluids. It is often used to estimate the physical properties of the rocks by combining seismic and well-log data. Physical parameters of interest are the impedance, velocity and density. Some form of forward modeling is used to generate the earth's response to a set of model parameters using mathematical relationships. Using inversion, an image of acoustic impedance for normal incidence reflection can be generated.

Acoustic impedance (Al) is the product of rock density and P-wave velocity. Acoustic impedance inversion is thus simply the transformation of seismic data into pseudo-acoustic impedance logs at every trace. All information in the seismic data is retained (Latimer et al, 2000). Inversion results showed high resolution, enhanced interpretation techniques and reduced drilling risk (Pendrel, 2006). Post-stack inversion can be divided into two main approaches: band-limited (iterative) inversion and broad-band inversion, which in turn includes the model-based and sparse-spike approaches (Russell and Hampson, 1991).

Model Based Inversion

A model-based deconvolution was used to invert the stacked sections to pseudo-velocity sections. The model-based inversion derives the impedance profile which best fits the modeled trace and the seismic trace in a least squares sense using an initial guess impedance. Basically, this inversion resolves the reflectivity from an objective function and compares its RMS amplitude with the assumed reflectivity size. The wavelet is then scaled to compensate for the difference. This iterative process for updating the estimated reflectivity requires an initial impedance value. The initial impedance logs were obtained from the sonic and density logs of the wells A, B and C.

Each value of the mean impedance log obtained from the three wells (A, B, and C) corresponded to the arithmetic sum of the individual impedance values for each well divided by the factor 3. During this process each well was stretched for matching the principal impedance contrasts with the formation tops associated with the D2000 formation at the tie location.

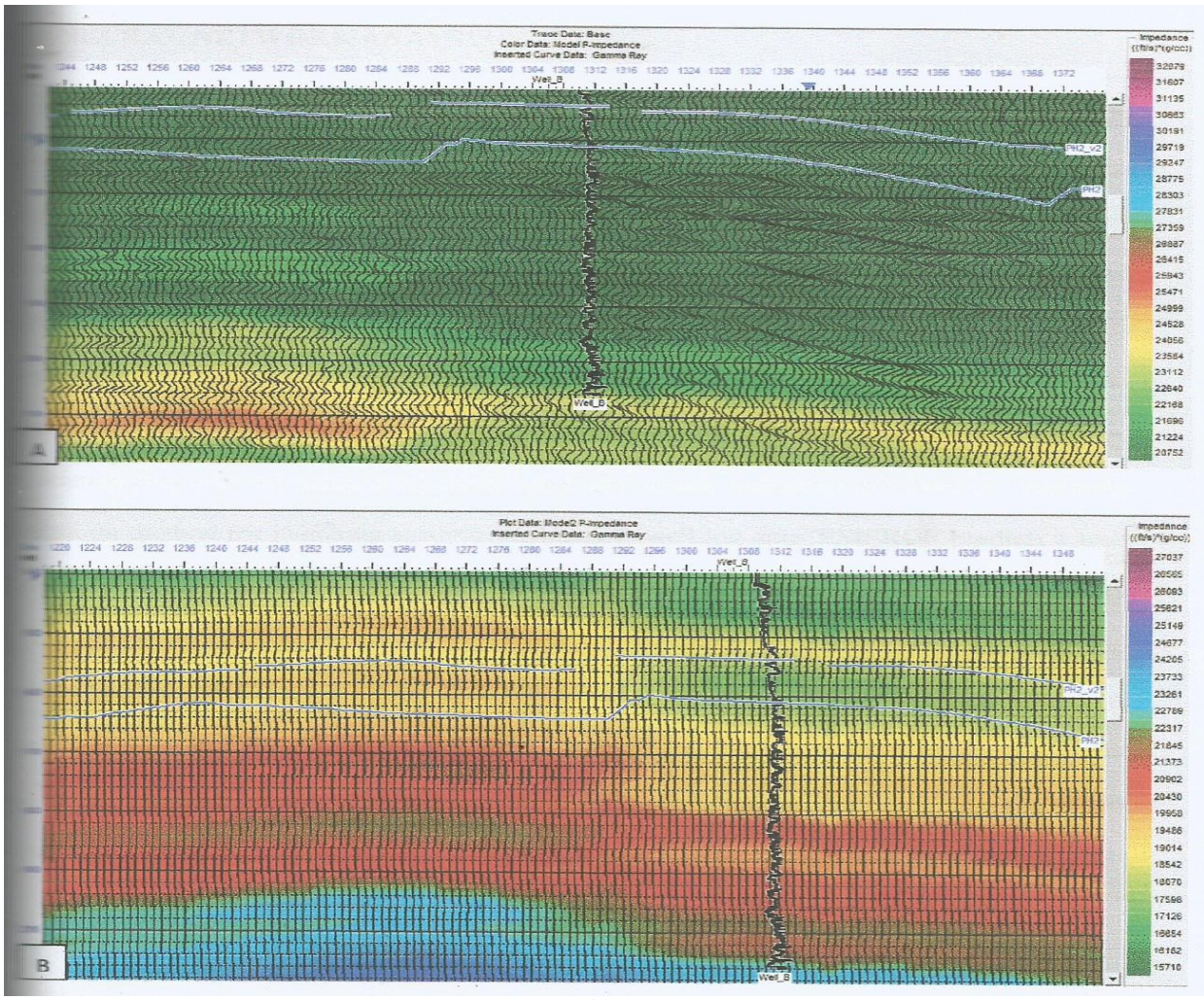

Fig. 8. Model based acoustic impedance section for (a) Base and (b) with PH2-V2 and PH2 horizons.

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III. Results and Interpretation

Analysis of Bulk Density Slices

Density values ranging from l.8-2.lgfcc are considered low while density value above 2.1 Ig/ce represents high values. Around the producing well locations in figure 4.6, slices of bulk density of both PH2_v2 and PH2 horizons obtained from the Base volume, was observed to be low indicating hydrocarbon sands since hydrocarbon is less dense than brine. However, on the Monitor, which has time-lapse effect, there was remarkable increase in bulk density especially around the wells on P1-12 horizon when compared with the Base as hydrocarbon is Deen replaced with brine. HCI and HC2 zones are probable bypassed hydrocarbon sand

Analysis of Vp/Vs Ratio Slices

Vp/Vs values here between the Base and Monitor porosity slices of both PH2_v2 and PH2 horizons are shown in figure 4.7. Here, low values of this attribute were observed on the Base volume of both horizons. Relative increase observed on the Monitor within and around the producing well locations with regard to fluid substitution can be attributable to hydrocarbon withdrawal and increase in effective pressure. Vp/Vs ratio also indicated sand formation.

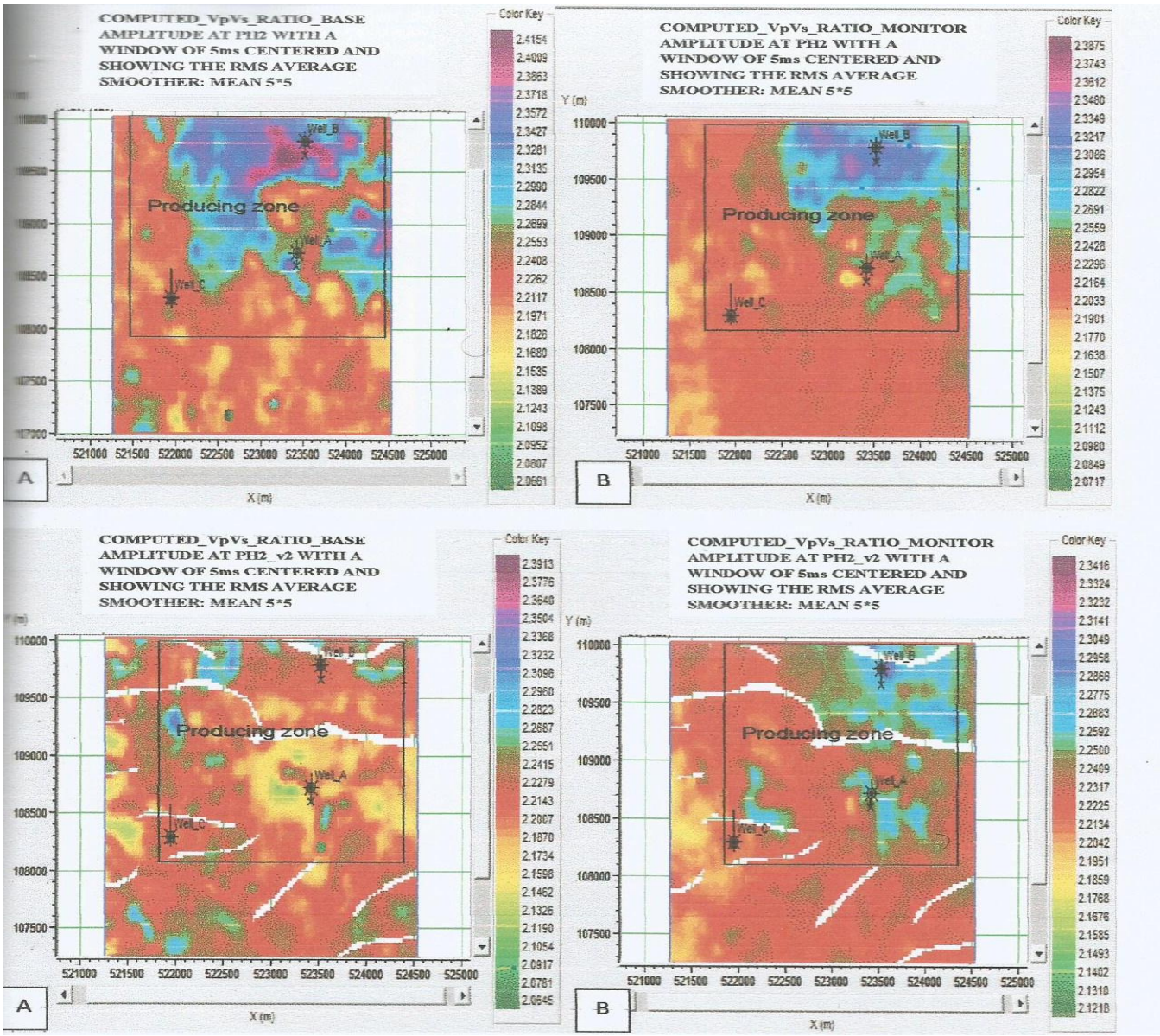

Fig. 9. VpVs Ratio Slices of PH2 and PH2-V2 horizons on (a) Base and (b) Monitor.

IV. Conclusion

This study was carried out to evaluate time-lapse (4D) production of hydrocarbon using some rock properties and attributes from available well logs and seismic data in a Niger Delta field. Various cross-plots were initially performed where results showed that P-impedance, lambda- rho density, poison's ratio and mu-rho attributes were more robust in terms of fluid and lithology discrimination as they exhibit high sensitivity to fluids within the reservoir while Vp/Vs ratio was

poor attribute in fluid discrimination. Gassmann's fluid substitution analysis also showed that density, lambda-rho and P-impedance were more sensitive to oil and gas saturations.

The attributes extracted from the Base and Monitor seismic volumes showed similar characteristics in terms of fluid sensitivity. On both seismic horizons (P1-12_v2 and P112), there was observable changes of the attributes in the Monitor over the Base. The degree of change is as a result of hydrocarbon withdrawal/production from the reserviour between the time of acquisition of the Base and Monitor, and its subsequent replacement with brine. There was however, a departure of this trend in the extracted porosity slice where no observable difference was noticed.

Hence, the use of rock properties and attributes has proved to be an efficient and effective means to investigate fluid changes as well as reservoir properties as hydrocarbon is produced over time. Through this technique, possible bypassed hydrocarbon as well as new reservoirs can be further evaluated and explored thereby increasing reserve and production.

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