Seismic Attributes Analysis for the Identification and Characterization of Hydrocarbon Reservoirs - Revisiting the Viking Graben dataset

Jorge A. T. Monroe, José J. S. de Figueiredo and Leo K. Santos, Federal University of Pará & INCT-GP

This paper was prepared for presentation at the International Congress of the Brazilian Geophysical Society, held in Rio de Janiero, Brazil, August 3-5 2015.

Abstract

In the characterization of hydrocarbon reservoir most of the methods used in rock physics or seismic reflection are based on the physical properties analysis of rocks which are associated to anomalous effects in seismic sections. These anomalies are, most of the time, associated to indicators of fluids (oil, gas and water) in the hydrocarbon reservoir. In this work, we perform an study in order to characterize a hydrocarbon reservoir present in the 2D Viking Graben seismic data, North Sea. In addition to the seismic data, well-logs from two locations (wells A e B) also were used in our analysis. In our data set analysis, beyond to perform AVO analysis, V_p/V_s versus impedance (I_p) and $V_p/V_s - \phi$ we applied the trend angle methodology and well-logs data set analysis as well as Gassmann fluid substitution. Through AVO analysis in the re-processing of Viking Graben seismic data set, three anomalous zones with a high potential for the presence of fluids (gas/oil) were found. Beyond that, was used templates of rock-physics and the analysis by attributes (trend angle) to classifying the fluids and determinate the possibility of gas-sand that are present at wells A and B.

Introduction

Recently, estimates show that around 60% of oil and gas reservoirs in the Earth's subsurface are contained in in unconventional reservoirs like carbonate and/or shales rocks (Weiwei, 2011). However, it is important to note that the increase in efficiency in the exploitation of oil reservoirs (for any type of rock) is a direct consequence of better knowledge of the physical and petrophysical properties that favor and disfavor the fluid flow, distribution of oil saturation and the type of medium (isotropic or anisotropic), or which is present in this fluid. It is known that seismic velocities and elastic parameters (shear moduli and bulk modulus) depends on the overburden, confining and pore pressures and petrophysical parameters of the medium (micro/macro porosity, permeability etc.). Understanding these dependencies is important step for interpretation and inversion of a seismic data with reliably (Ciz and Shapiro, 2007). There are several methods for the study of static and dynamic properties of fluids in reservoirs and most of these studies focused on the integration of information originating from pluggins data, well, seismic and knowledge of the depositional related to the reservoir system. However, the biggest challenge is the characterization of fluid presence in reservoirs are variables such as oil or water saturation which the response of fluid saturations can shows different values fro scales of laboratory dats, well-logs and seismic data. In the oil industry, many situations requires the detailed behavior of fluids in the reservoir (Khan and Jacobson, 2008).

For this proposal the use of indirect methods such as seismic reflection and rock physics are preponderant to characterize rock fluids in a reservoir (Khan and Jacobson, 2008). Both seismic and rock physics are most commonly used to investigate the influence of rock properties in the elastic wave propagation. Using analysis such as AVO technique (Amplitude Versus Offset) it is possible to detect possible candidates to hydrocarbon reservoir from seismic section. A manner to characterize the fluids contained in a reservoir is through (i) ultrasonic and petrophysical measurements of pluggings, (ii) using different type of well-log data and from (iii) seismic data. In the practice the characterization is complex and requires the development and analysis of multidisciplinary areas. The selection of techniques and procedures depends mainly on the type and quality of information to be handled (Tyson, 2007).

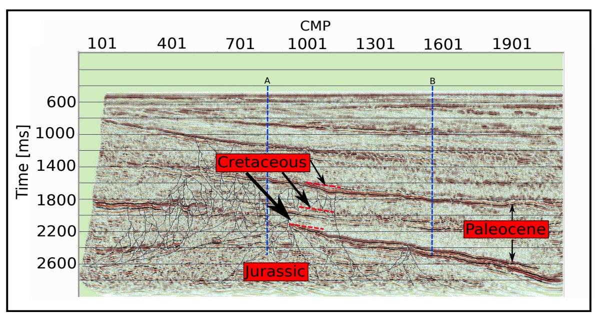

Figure 1: Time migrated and interpreted seismic section of the study area, where the main geological structures, faults, anomalies and geological facies are shown.

Seismic and Well Data Preparation

There are two difficulties with the hydrocarbon characterization in the Viking Graben data set. The first one, is the complexity itself of the Viking Graben region. The second and most important, is the discrimination of hydrocarbon-bearing sands from shale and the separation of gas sands from water-saturated matrix. For overcome the difficulties presented in to image the Viking Graben region, a carefully processing and re-processing of seismic data were performed (Figure **??**). The operations constituted in repositioning of the data in the true geometry, data filtering (because the data present an environment with low s/n ratio) and the creation of a reliable velocity of migration. An affordable velocity model was reached through the velocity picking every 5 CMP. In this way, a velocity model with the best sampling rate was achieved. in the velocity model also can be seen that the variations in the contrast of velocities from 2000 ms to 3000 ms have less separation, this is the result of having an environment highly fractured. Due to in the well log of the S-wave velocity has showed gaps, was necessary create a new well logs, for which the two different types of mathematical relationships from Castagna et al. (1985) were taken, the first is a linear relation, which the relation of Vp velocity with a Vs velocity by a numerical constant ($V_{cs}^{(1)}$ in equation 1), and the second is a quadratic relationship, which relating the Vs velocity and Vp velocity by three numerical constants ($V_{cs}^{(2)}$ in equation 2). The sonic porosity was estimated by Wyllie's equation (Gregory et al., 1958) (see equation 3).

$$V_s^{(1)} = \frac{V_p - 1.36}{1.16}; \tag{1}$$

and

$$V_s^{(2)} = -0.1236V_p^2 + 1.6126V_p - 2.3057. \tag{2}$$

and

$$\phi_{sonic} = \left(\frac{\Delta_p^{log} - \Delta_p^{matriz}}{\Delta_p^{fluid} - \Delta_p^{matriz}} \right) C_f; \tag{3}$$

where C_f, Δ_p^{log}, Δ_p^{matriz}, Δ_p^{fluid} and ϕ_{sonic}, are compaction factor (fractional), sonic log read in zone of interest (μsec/ft or μsec/m), sonic log read in 100% matrix rock (μsec/ft or μsec/m); sonic log read in 100% water (usec/ft or usec/m) and porosity from sonic log (corrected for compaction if needed) (fractional) respectively.

AVO Analysis

In this study, the AVO analysis technique was applied for CMP sections of wellbore A and B and Figure 2), also the AVO analysis was applied to the seismic section in order to relate the results (see Figure 2); consequently three anomalous areas were obtained, two anomalous zones near-wellbore A, and at the last in the CMP 600 and as a result of this the anomalous zones encountered during application of analysis by attribute (trend angle) were confirmed. For the Figure 3a and Figure 3b a comparison between the synthetic seismogram, the seismic section seismogram and the AI log are shown, in order to relate the good well tie obtained by vary the distance of the offset (ranging from 5 to 30 degrees); as a result of this we can see that the amplitudes decrease indicating the presence of an area with different physical properties.

As shown in Figure 4a we can see that the AVO analysis of data from the well A confirms the presence of hydrocarbon, due to the crossplot that shows anomalous points belongs to the class IV of AVO classification indicating the presence of gas sands, though also can be seen that most of the data belongs to class II (in classification of the AVO analysis seen in point 2.6.1), which indicates the presence of formation water present. By the other hand, for the Figure 4b it is possible to confirm the presence of formation's water in the well B because of the crossplot shape,

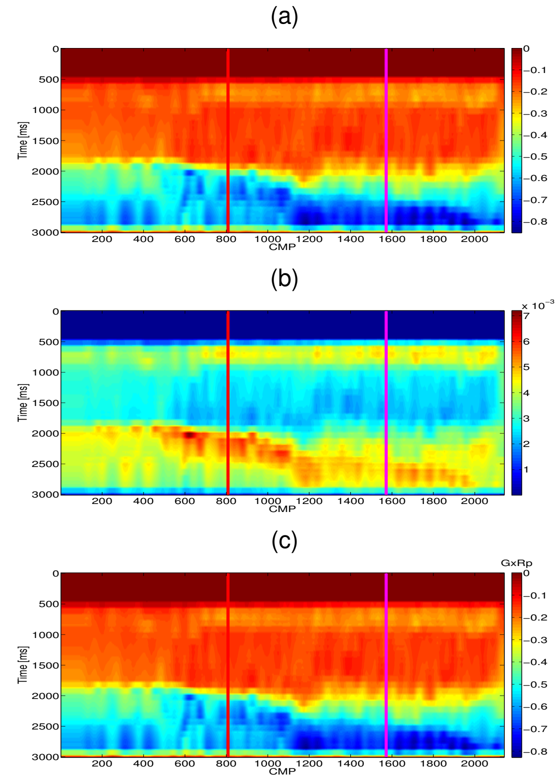

Figure 2: (a) Seismic gradient map where we can see the anomalous zones is present in the CMP 600 and in the area near the well A. (b) Intercept seismic map derived from the application of the AVO technique to seismic section. (c) Map of seismic AVO attribute related to seismic section, it can be note that anomalous zones are related to areas with high rate of fracturing.

although there are some anomalies belongs to class IV, due to the fractured environment which generates this phenomenon called "false positive", therefore to confirm the results obtained from the AVO analysis in the well A, an AVO analysis to the seismic section was performed (specifically in the area of the well A), which confirmed the results showing that in the area near of well A there is a high probability of containing hydrocarbon (Figure 2).

Trend Angle

Rock physics has emerged as a tool for geophysicists to characterize reservoir properties as they pertain to seismic elastic parameters. In addition, rock physics models have been presented that relate sedimentology and rock fabric to changes in elastic properties. In this paper we have implemented a new seismic attribute called trend angle. The trend angle (eq. 4) is a new technique of rock physics that quantifies the angle trend among neighboring data points in a rock physics.

$$\alpha = \arctan \left[\frac{\Delta AI}{\Delta \left(\frac{V_p}{V_s} \right)} \right]; \tag{4}$$

where ΔAI are variations in acoustic impedances of two adjacent formations, $\Delta \left(\frac{Vp}{Vs} \right)$ are variations in the P-wave velocity and S-wave velocity of the same two adjacent

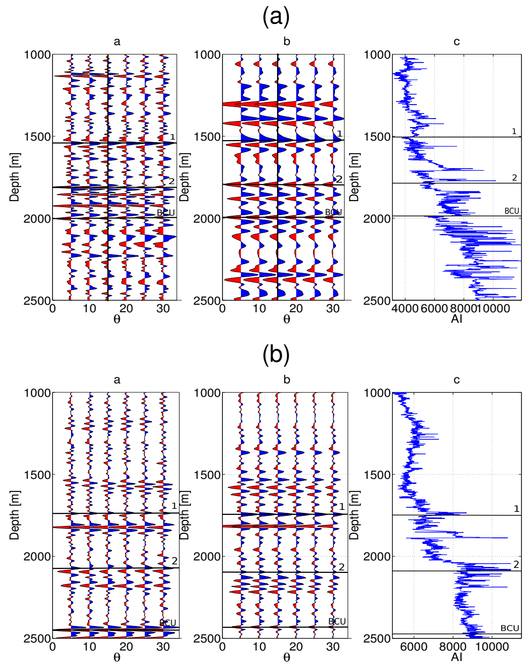

Figure 3: Comparison between synthetic seismogram, real seismograms and AI log: (a) Well A and (b) Well B.

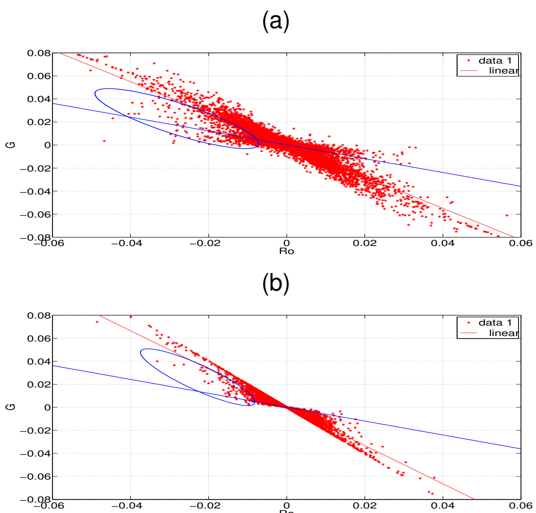

Figure 4: AVO analysis from well A, showing the trend of the data, which can infer the presence of gas sand classification of the fluids contained in the well A.

formations and α is the attribute value. The maximum values are between the values of -90 to +90 degrees. This attribute is shown conceptually in Figure 5 (Avseth and Veggeland, 2014).

For this paper, we take the units of AI in kilometers per second times grams per cubic centimeter $(Km/s * gr/cm^3)$ to avoid extreme fluctuations between the limits for any point. The concept of the trend angle is similar to the AVO attribute defined by Regueiro and Gonzalez (1995) or the polarization angle defined by Castagna et al. (1985). However, this approach is more easily performed by the relationship between the attribute and changes in rocks-physics properties, because the analysis is performed in the domain AI-versus-Vp/Vs.

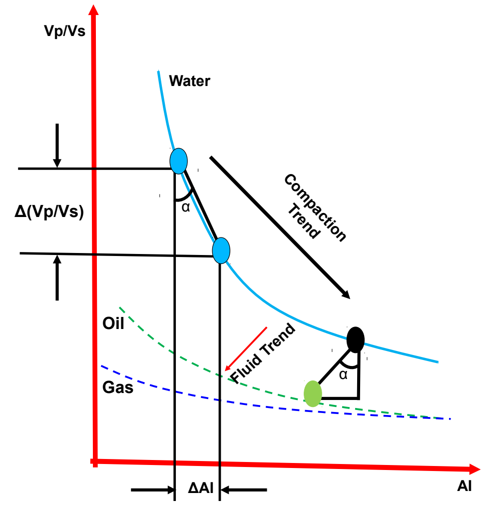

Figure 5: Illustration of trend angle method applied to the elastic parameters, wherein the fluid content variation is shown relative to the porosity and physical parameters variation.

In our approach, we can more easily relate the attribute to changes in rock-physics properties, because we operate in the AI-versus-V_p/V_s crossplot domain (see Figure 8). Thus as seen in Figure 8, while a lower AI value and higher values in V_p/V_s, the value of porosity will be greater. The Figure 8 is a template, to highlight the effect of the matrix (cement) within the reservoir. Gas-saturated sands, are typically well separated from brine-saturated sand, in the rock-physics crossplot of V_p/V_s versus AI. This effect could reduce the fluid sensitivity, this would cause, in the model, an overlapping between brine and oil data. As result, this can cause a well-know ambiguity between poorly sorted loose sands with hydrocarbons and well-sorted cemented sandstones saturated with water (Avseth et al., 2005). However the AI will increase, so the trend in a rock-physics template will be different from a fluid trend (see Figure 8). The corresponding trend angle are estimated between each point shown in Figure 6(a) and are displayed in color. We also plot the data points as a function of depth (as shown in Figure 6(a)(a)) where we include the plot of trend angle as a separate log (see Figure 6(a)(c)). In this log two posibles zones with gas-sands are easily detectable from the matrix, because are the maximum picks in the rigth side. In addition to test the effectiveness of the attribute trend angle, in the seismic section, were applied techniques of AVO analysis which is shown in Figure 2(a) and Figure 2(b), where we can confirm the anomalous zones.

During application of the techniques of re-processing was found a amplitude anomaly (in CMP 600) showing a like bright spot on the impedance map at time approximately in 2000 ms (see Figure 7(a)); in addition to, the same anomalous zone it is appreciated as an area of low amplitude on the AVO map (see Figure 2), intercept map (see Figure 2(b)) and gradient map (see Figure 2(a)). As the result the V_p/V_s ratio could be used to separate between unconsolidated clastic sediments (V_p/V_s

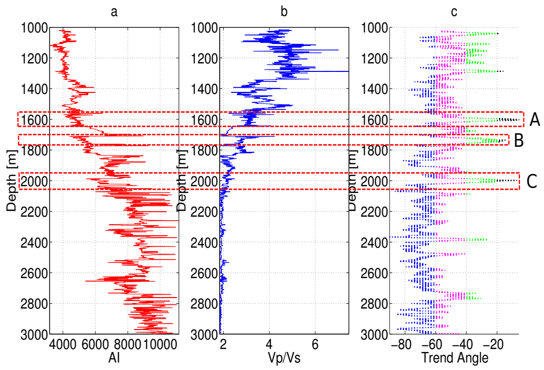

Figure 6: Logs showing the three main anomalous zones found by the trend angle technique, which are compared with the logs of acoustic impedance and V_p/V_s ratio.

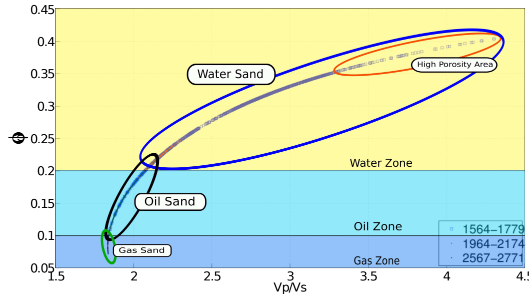

Figure 9: Empirical relationship Vp/Vs and ϕ, where the relationship of the porosity, the Poisson's ratio and type of fluid content are sorting.

$\geq$ 2.0) and consolidated or gas-filled unconsolidated clastic sediments ($V_p/V_s \leq$ 2.0) (Gregory, 1977).

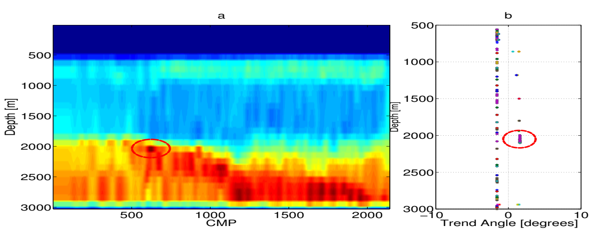

Figure 7: The application of the technique of angle trend used in the anomalous zone present in approximately 2000 ms and CMP 600, the log presented was performed by creating a pseudo-well, where were found the physical parameters necessary for the application of the technical trend angle: (a) impedance map and (b) angle trend log.

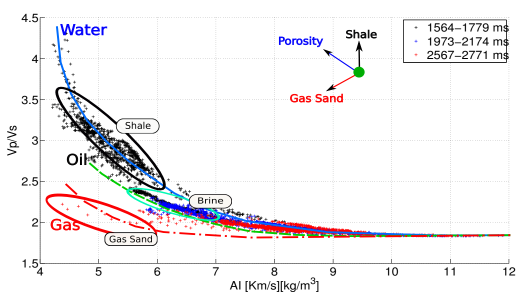

Figure 8: Template that shows the behavior of the physical properties compared to the elastic properties, where the type of fluid present is classified.

This anomaly could be sands interbedded with shale, because of the impedance and V_p/V_s values have a gradation with sand/shale ratio (as shown in Figure 9). As a validation of the results found in the maps of AVO and reflectivity was made an analysis by attributes (trend angle), as result is shown a low Vp/Vs ratio and a trend angle variation from -2 to 2 degrees, suggesting a gas sand (Ostrander, 1984) or limestone (Hilterman, 2001) with the unconsolidated gas-sand interpretation (Gregory, 1977) being supported by the low values on the ϕ (as can be seen in Figure 9), would therefore confirmed the presence of the anomalous zone present in the CMP 600, which has high probability of contain hydrocarbon, as is shown in Figure 7b, further showed that the fractured environments have a very low influence on the trend analysis angle.

Conclusion

In this work was possible to get a better understanding of the characteristics of the data and of the techniques for reservoir characterization, identifying key steps to get the best possible results. In general, from interpretation and results obtained from trend angle and AVO techniques demonstrate that seismic section from Viking Graben area have three different anomalous zones with presence of hydrocarbon, although different techniques have been applied to the seismic data the results confirm the presence of fluids. With AVO analysis the three different anomalous zones locations were found in the CMP's 600, 810 and 850 With AVO analysis the three different anomalous zones locations were found in the CMP's 600, 810 and 850. Due the type of anomaly and behavior, they indicates a high potential for the presence of fluids (oil, gas or/and water). Because of the historical accounts of the area there is a high probability that the new anomaly found (at CMP 600) to be gas.

Also the results showed a way to discrete, to some degree, the presence of fluid detected in the wells A and B, using templates of rock-physics and attributes analysis (in this case the trend angle), which it have a high probability to contain gas sand. Additionally, it was shown that the methods used: (a) trend angle and (b) rock physics template can be discretized in some degree the type of fluid present in the reservoir, due to that provides information on the interaction of fluids with the rock matrix. This approach provides a new way of discretization of the fluid contained in the sub-surface, which quantifies the trend angle in the data and highlights the anomalies of the fluids, even at low values of V_p/V_s.

Acknowledgments

We would like to thank Exxon Mobil for kindly provides the seismic and well data and the Federal University of Para and INCT-GP- Brazil, who partially supported the development of this work.

References

Avseth, and Veggeland, 2014, Seismic screening for hydrocarbon prospects using rock-physics attributes: SEG, **33**.

Avseth, P., T. Mukerji, and G. Mavko, 2005, Quantitative seismic interpretation applying rock physics tools to reduce interpretation risk: SEG.

Castagna, J., M. Batzle, and R. Eastwood, 1985, Relationships between compressional-wave and shear-wave velocities in clastics silicate rocks: Geophysics, **50**, 571–581.

Ciz, R., and S. Shapiro, 2007, Stress-dependent anisotropy in transversely isotropic rocks: Comparison between theory and laboratory experiment on shale: Geophysics, D7–D12.

Gregory, A., 1977, Aspects of rock physics from laboratory and log data that are important to seismic interpretation: exploration AAPG, **26**, 15–46.

Gregory, A., L. Gardner, and M. Wyllie, 1958, An experimental investigation of factors affecting elastic wave velocities in porous media: Geophysics, 459–493.

Hilterman, F., 2001, Seismic amplitude interpretation: Soc. Expl. Geophys.

Khan, S., and S. Jacobson, 2008, Remote sensing and geochemistry for detecting hydrocarbon microseepages: Geological Society of America Bulletin, **120**, 96–105.

Madiba, G., and G. McMechan, 2003, Processing, inversion, and interpretation of a 2d seismic data set from the north viking graben, north sea: Geophysics, **68**, 837–848.

Ostrander, W., 1984, Plane-wave reflection coefficients for gas sands at nonnormal angles of incidence: Geophysics, **49**, 1637–1648.

Regueiro, J., and E. Gonzalez, 1995, A different seismic avo attribute for fluid-lithology identification: SBGf.

Tyson, S., 2007, An introduction to reservoir modeling: Pipers' Ash, Limited.

Weiwei, L., 2011, Seismic wave propagation in fractured anisotropic carbonate rock: Experiments and theory: Geophysics.