Case Study: Seismic Velocity Anomalies Analysis for Gas Detection in Potiguar Basin

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Abstract

This paper will present a methodology to analyze the 3D seismic velocity behavior with well data support, and the misfit of these velocity curves from a normal compaction velocity trend. In this work was used five wells and one 3D survey from the Potiguar Basin. The methodology involves extracting the best velocity trends from seismic and well data and other correlation functions before removing the trend to obtain the residuals. As a result, the application has proved to be able of to separate low velocity zones associated to gas anomalies from lithological anomalies and/or velocity artefacts.

Introduction

A geologically consistent velocity model is characterized by its adequate correlation with the structure of the layers, i.e., conforming to the geological formation, considering lithological contrasts, folds, and faults. The layers may be parallel to the topography or bathymetry structures in regions of ductile rocks, and velocity variation may be primarily a function of burial (Schultz, 1999). It must include all the available velocity information, adequately sampled, duly weighing its different types, seismic and wells to be the most reliable (Etris *et al.*, 2001; Bulhões *et al.*, 2014).

The velocity analysis is a tool used for the inference of pore pressure anomalies in 2D and 3D seismic surveys. In most cases of seismic velocity analyzes, the changes detected at the interval velocity are related to lithology, porosity, pore fluid type and pressure changes within the stratigraphic column.

Due to the compaction during the burial of the geological layers, the interval velocity of the siliciclastic rocks increases with depth (Avseth *et al.*, 2001). However, there are anomalies in the trend of interval velocity across the depth, which can coincide with the beginning of zones of abnormally high pore pressures (Chopra and Huffman, 2006). The pore pressure (or formation pressure) is defined as the pressure acting on the fluids in the pore space of a formation (Chopra and Huffman, 2006). The phenomenon occurrence of lithostatic pressure correlates well. Also, in most cases with some geological mapping characteristics, such as changes in lithology, sediment deformation, and faults. The rocks with high pore pressure have low velocities (Figure 1). This is due to the stress on the pores that decreases the area of contact between the grains. Thus reducing the efficiency of the propagation of energy through the medium (Chopra and Huffman, 2006).

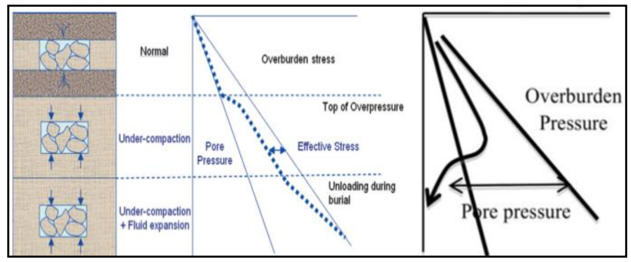

Figure 1: Effect of effective vertical stress to different subsurface conditions.
Source: Adapted from Chopra and Huffman (2006), Soleymani and Seyedali (2006) and Brower (2002).

Potiguar Basin

The baseline gas assets or the anomalously pressurized gas accumulation represents a relatively unexplored Brazilian energy potential. Converting these energy resources into viable gas reserves is a particularly costly task. Traditional exploration and production techniques are relatively ineffective since gas accumulations at anomalous pressures are not necessarily confined to conventional structural and/or stratigraphic traps (Figure 2).

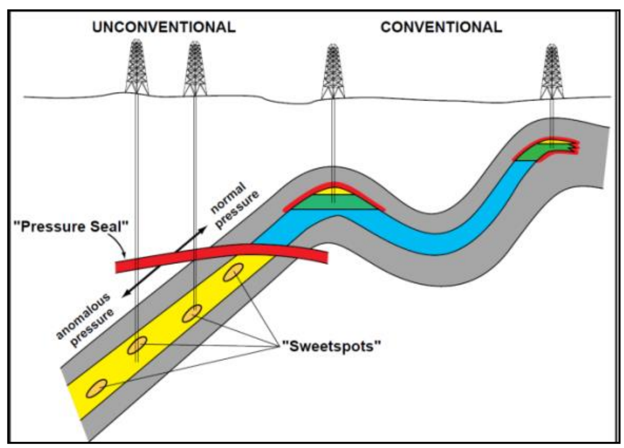

Figure 2: Schematic diagram illustrating of the two elements crucial to hydrocarbon exploration in gas saturated anomalously pressured rocks: (1) the pressure boundary (i.e., regional velocity inversion surface) and (2) sweet spots.
Source: Surdam et al. (2000)

In the onshore Potiguar Basin (Figure 3), the characterization of this type of reservoir is still in a developing phase, and data concerning the areas of Riacho da Forquilha, Cachoeirinha and Marizeiro (Alves *et al.*, 2008; Lira *et al.*, 2018) were analyzed. The reservoirs with low porosity (less than 10%) and low permeability (less than 1.0 mD) deposited by gravitational fluxes in a lacustrine environment. Also, some of these reservoirs being formed by sandstones and conglomerates with low porosity (usually less than 10%) and low permeability produced gas.

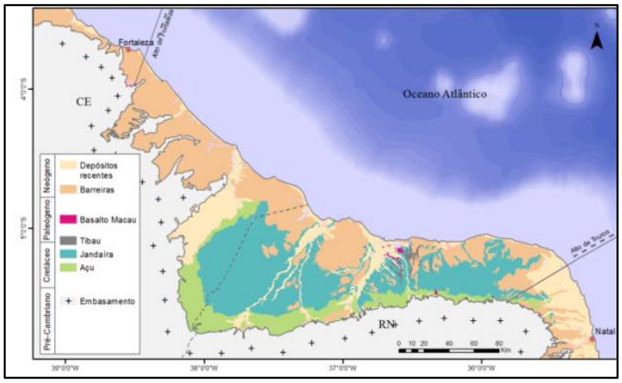

Figure 3: Location of the Potiguar Basin.
Source: Mohriak (2003).

Methodology

Surdam et al. (1997) developed a new strategy to help reduce the risk of investigating accumulations of gas with pressure anomalies. This exploration strategy is based on a new conceptual model in the evolution of abnormally pressurized gas resources in the Rocky Mountain basins. Efforts to use the conceptual model resulted in the formulation of a new paradigm for exploiting abnormally pressurized gas resources (Surdam, 1997). This paradigm emphasizes that two elements are crucial for the development of perspectives in the relatively deep and saturated portions of gas: 1) determination and, if possible, 3D evaluation of the pressure limit (or velocity inversion surface) between pressure regimes normal and anomalous; and 2) the detection and delineation of porosity and permeability sweet spots (areas of higher storage capacity and delivery capacity) at potential reservoir targets below this limit. These two elements are essential to reduce risk and ensure the successful exploitation of unconventional gas resources present in anomalously pressurized rock-fluid systems.
The 3D analysis of well velocity, residual well velocity and intervals as a function of tectonics and regional block stratigraphy; can be used to:

(a) Delineate the regional velocity inversion surface, or the depth at which the observed velocity value begins to be significantly lower than would be predicted at that depth by the velocity trend as a function of the ideal regional depth. For example: pressure, which separates the usually dominated pressure of water from the pressure dominated by gas-saturated zones.

b) Efficiently isolating gas saturated rock-fluid systems like abnormally low velocities;

c) Quantify the magnitude of the velocity anomaly by comparing it with a regional velocity trend function by depth (or time) which allows the velocity anomaly to be compared horizontally and vertically. The quantification of abnormally low-velocity values is essential for delineating the gas distribution and for detecting gas migration routes. It can be done by removing the ideal velocity/depth function from the observed velocity/depth log.

Example: Jonah Field

Surdam *et al*. (2000) present an example of the velocity trend calculation performed at Jonah Field, located in Sublette County, Wyamong State, United States. This field is a significant producer of natural gas in the Green River basin. In Figure 4 is observed the analysis of the trend and the estimated velocity anomaly from the reading of the sonic log. The abnormality is evidenced by the withdrawal of the velocity trend obtained in the sonic log, and a low-velocity anomaly is observed.
It is possible to further isolate and visualize the anomalous velocity characteristics of the Jonah area by removing all parts of the volume with abnormal velocities less than 1600 m/s. This leaves a remaining volume with negative anomalies of velocities greater than 1600 m/s below the regional velocity gradient as a function of depth or time (Figure 5). On surfaces of negative velocity anomalies, these vary from 1200 m/s to more than 2000 m/s below the regional velocity gradient. This operation gives exploration geoscientists a very important visualization tool: velocity variations within intervals of reservoirs.

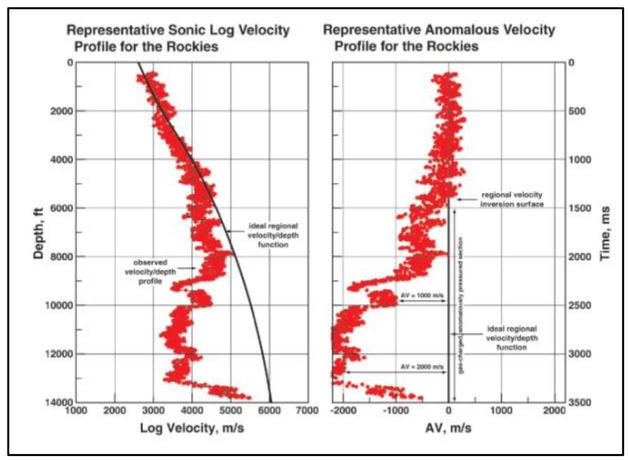

Figure 4: On the left panel are an observed sonic velocity profile (red) and an ideal regional velocity/depth trend (black). On the right panel, the ideal regional velocity/depth trend has been removed from the sonic velocity log. The vertical black line is the ideal regional velocity/depth trend.
Source: Surdam (2003).

Ferreira *et al.* (2018) adapted the methodology proposed by Surdam *et al.* (2000) for application in 2D seismic surveys of the Parnaíba Basin (Figure 6).
Experience indicates that velocity analyzes from the sonic log and seismic data are extremely useful in assessing the pressure limit and "sweet spots." the regional trend remotion of velocity as a function of the velocity-depth obtained from the sonic log highlights the stratigraphic zones with rocks saturated of gas. The resulting abnormal velocity log generates the best evidence and delineates anomalously low velocities. Therefore the gas distribution with anomalously low velocities generally indicates the presence of gas.

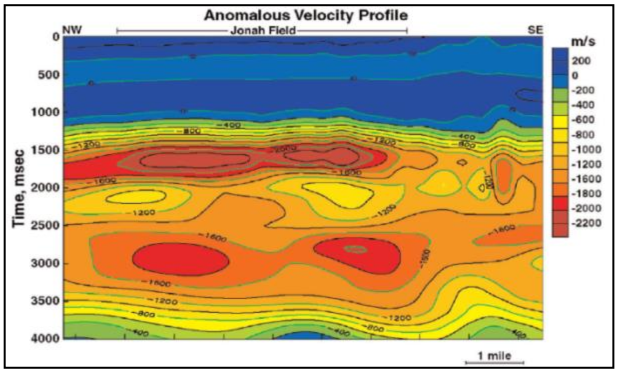

Figure 5: Anomalous velocity profile constructed by removing the regional velocity/depth gradient. Note the improved resolution with respect to the position of the velocity-inversion surface and the delineation of the velocity anomalies below the velocity-inversion surface.
Source: Surdam et al. (2000).

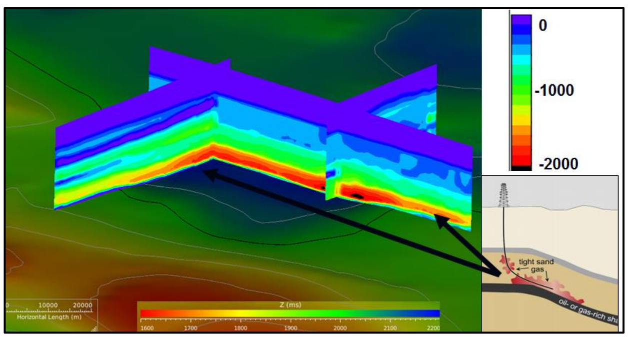

Figure 6: Velocity anomalies with lower values when compared to horizons representing deeper events in the Parnaíba Basin may indicate possible Tigh gas reservoirs.
Source: Ferreira et al. (2018) and Hussein (2017).

The equation 1 used in the linear regression where the velocity trend and the residual velocity are presented.

$$V = V(Z) = V_0 + V_{trend}(Z) + V_{res} \quad (1)$$

$$V(z) = V_0 + kZ + V_{res} \quad (2)$$

Where:

V_0 is the velocity intercept;
k is the time/depth velocity variation gradient;
V_{res} is the residue of velocity.

V_{res} can be described as:

$$V_{res} = V_{lito} + V_{fluido-poro} + V_{proc/aq} \quad (3)$$

Where:

V_{lito} is the velocity anomalies of the lithologic source;
$V_{fluid-poro}$ velocity anomalies due to the presence of fluids and porosity;
$V_{proc/acq}$ are anomalies arising from acquisition and processing artifacts.

Results

The trend and residual calculation workflow were applied to the 3D processing velocity data and the velocity profile in the wells. Fig. 7 shows the inline and crossline sections representation of the residue calculated from the removal of the trend of the velocity volume, together with the regional horizon. The largest negative anomaly values are represented in red in the seismic sections. In the cross plots of Fig. 8 the residues are represented, where negative anomalies of up to 1500 m/s are observed.

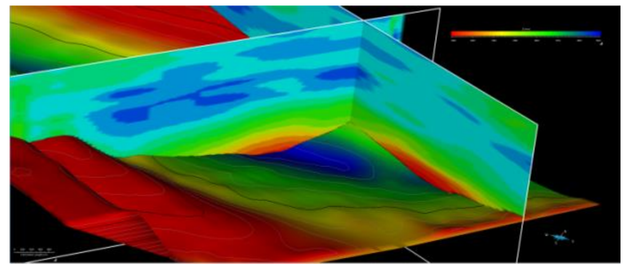

Figure 7: Lower velocity anomalies when compared to horizons representing deeper events in the Potiguar Basin, which may indicate possible Tigh gas type reservoirs.
Source: The authors (2019).

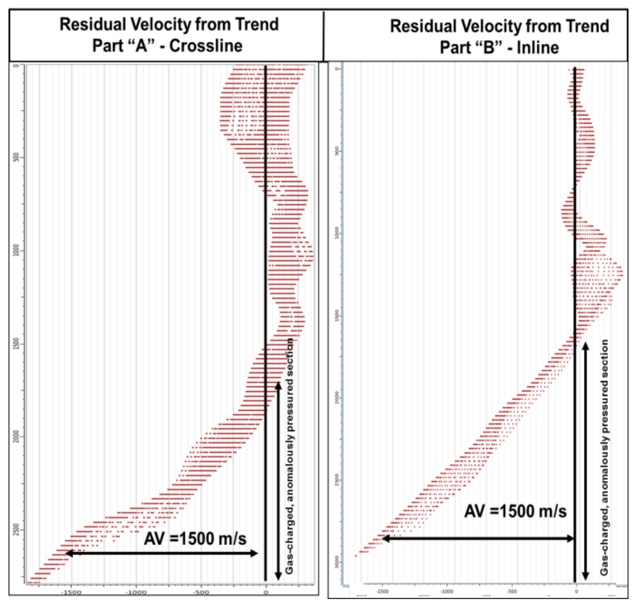

Figure 8: Residuals profiles (difference between interval processing velocity and regional trend) of crossline part "A" and inline part "B".
Source: The authors (2019).

It was also analyzed whether the same response occurs at the rate calculated from the sonic log in Fig. 9 is the velocity log in black and the trend calculated in green (track 1) and the residue derived in red (track 2). A negative velocity anomaly of the same magnitude estimated at the 3D velocity in the same stratigraphic zone (Figs 7 and 8) was observed in the residue profile. Another important point is that this negative anomaly correlates strongly with a substantial increase in the value of the neutron profile in blue (track 3).

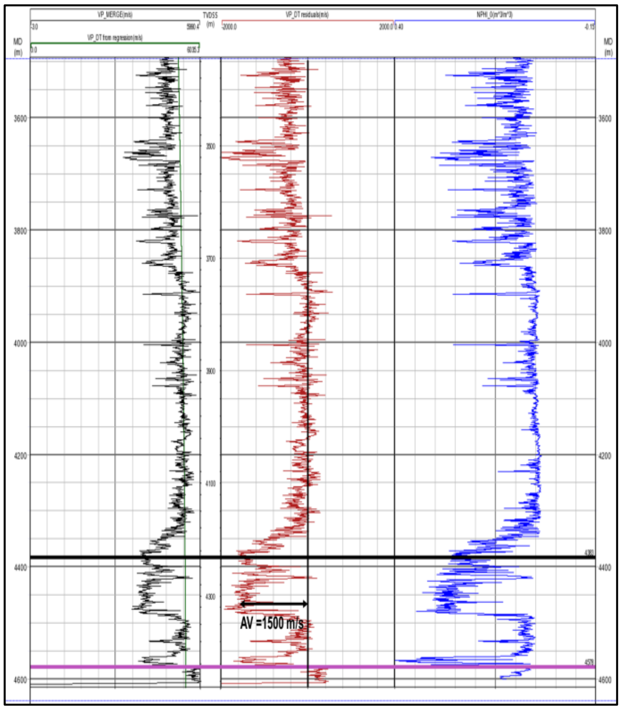

Figure 9: Logs of the "C" well. (a) calculated Vp log of the sonic (black) and regional trend (green). (b) Residual calculated (difference between Vp and trend). (c) Neutron log.
Source: The authors (2019).

The next step in gas and distribution evaluation is to estimate anomalous velocity. Anomalously low velocities characterize volumes containing only rock-fluid systems. From the volume of residue calculated the value of anomalies created the filtering region. The applied filter was to detect anomalies smaller than -1000 m/s and is represented in Fig. 10 together with the regional map.

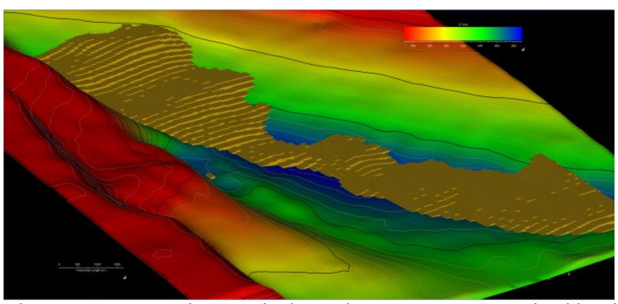

Figure 10: Anomalous velocity volume was removed with all rocks with abnormal velocities<1000 m/s. This volume represents the most intense velocity anomalies in the study. All rocks within this volume have velocities that fall 1600 m/s or more below the regional pressure/depth gradient.

Discussion and Conclusions

The application of the methodology proposed by Surdam *et al.* (2000) for the trend removal of the velocity data performed in the onshore portion of the Potiguar Basin presents a very promising response with promising results against the results obtained by Surdam *et al.* (2003) in the Jonah Field and for application in the Parnaíba Basin using 2D data and check-shots (Ferreira *et al*., 2018).

Isolation of the anomalously low velocities allows delineating the regional surface velocity inversion or the depth at which the observed velocity value begins to be significantly lower than would be predicted at that depth by the ideal regional velocity/depth function. The methodology also becomes more easily isolate gas-saturated rock-fluid systems (anomalously low velocities) and quantifies the velocity anomaly magnitude by comparing it with an analytical velocity function varying with depth. It represents the quantification of abnormally low-velocity values.

The correlation of these velocity anomalies with seismic attributes (coherence and curvature) can corroborate with the areas delimitation of possible gas accumulations.

Acknowledgments

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