From a regional AVA screening to focused elastic attributes estimation: an integrated solution from seismic acquisition to reservoir characterization.

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Summary

Understanding the elastic properties of reservoirs in exploration can be very challenging - due mainly to the lack of well information, limited regional geological understanding, and the quality and reliability of seismic data available.

This case study illustrates how this challenge can be addressed through an integrated solution from broadband seismic acquisition to elastic properties, applied recently to the underexplored deep-water Orphan Basin, offshore Eastern Canada.

A multisensor seismic dataset covering close to 22,500 km^2 was acquired over three seasons (from 2017 to 2019) and now constitutes a great platform for understanding the geology as well as extracting elastic properties.
The understanding of the prospectivity was performed at the regional scale, then on more localized area using one of the very few wells present in the area. On this localized area the newest depth imaging technologies with Full Waveform Inversion (FWI) and Least-Squares Migration (LSM) were used. In addition, a three term Amplitude Versus Angle (AVA) inversion was performed and matched at the well without using the well actively in the process but by using the broadband seismic data only: velocity and amplitude.

Turnaround time was also a key element in this regional project. To significantly reduce this, an integrated team of imaging and quantitative interpretation specialists was dedicated to the project from the start. Pre-stack AVO QC was performed iteratively during the processing to ensure that the final pre-stack data was fit for purpose and AVO/AVA compliant for further Quantitative Interpretation (QI) analysis.

Introduction

Reservoir geoscientists and quantitative interpreters gain a better understanding of the subsurface by integrating seismic and well measurements. In exploration, the lack of well information for calibration of the seismic response shifts the emphasis towards optimizing seismic data quality and doing so in a timely fashion to identify and derisk prospects as efficiently as possible. At the same time, more and more accurate imaging is required to resolve the detail of complex reservoir units and trapping configurations as petroleum geoscientists seek to identify and characterize subtler targets. Having seismic that is band-limited in frequency range creates an imperfect and distorted view and compromises characterization-quantification of the subsurface (Ozdemir, 2009; Reiser et al., 2012, 2016; Lafet et al., 2012; Kneller et al., 2018).

Higher resolution from seismic is not just a matter of high frequencies: to better detect and delineate features with high resolution requires a contribution of high and low frequencies. For example, lacking the low frequencies can lead to underestimation of the real thickness of a geological layer (Zabihi Naeini et al., 2017).

Offshore Eastern Canada, PGS, in partnership with TGS, has acquired three surveys in the Orphan Basin over the last 3 years (Figure 1). These 3D surveys together represent close to 22,500 km^2 of broadband multisensor streamer seismic complementing the already extensive Labrador and Newfoundland offshore 2D and 3D broadband seismic data library.

These surveys are now the base of a regional 3D prospectivity study over open blocks, integrating the only three nearby wells. These wells alongside the quantitative interpretation are helping understanding elastic characteristics of the two main reservoir intervals of interest: Lower Cretaceous and Upper Jurassic. This regional analysis has been complemented by a more detailed proof-of-concept workflow, around one of the wells, including advanced depth imaging techniques to obtain an improved velocity model as well as to sharpen fault imaging and improve the signal to noise ratio.
This case study discusses the main steps of this prospectivity analysis.

Geological settings

The Orphan basin (Figure 1), north of the very prolific Jeanne d’Arc Basin, is a very large basin of more than 150, 000 km^2 located in water depth ranging from 200 m to 4,000 m, in which a petroleum system has been established (Enaschescu, M et al., 2005) and presents excellent exploration potential.

The exploration targets over this area include Late Jurassic to Early Cretaceous fluvial to shallow marine sandstone reservoirs sourced by prolific oil-prone Late Jurassic marine shales (McCallum, D. et al., 2019). A mainly extensional margin provides large structural traps and thick regional seals. Potential reservoirs from Lower Cretaceous to Lower Tertiary are stratigraphically positioned above the Kimmeridgian source rock super highway.

Three wells are present in the region of the study (Figure 2): Great Barasway F-66 (drilled in 2006), Lona O-55 (drilled in 2010) and Margaree A-49 (drilled in 2013). These wells penetrated the Tithonian to Kimmeridgian interval and encountered the main reservoir (Upper Jurassic) and source rock in the area.
In the basin, there is clear evidence of AVO anomalies (McCallum et al., 2017) which are mainly class II.

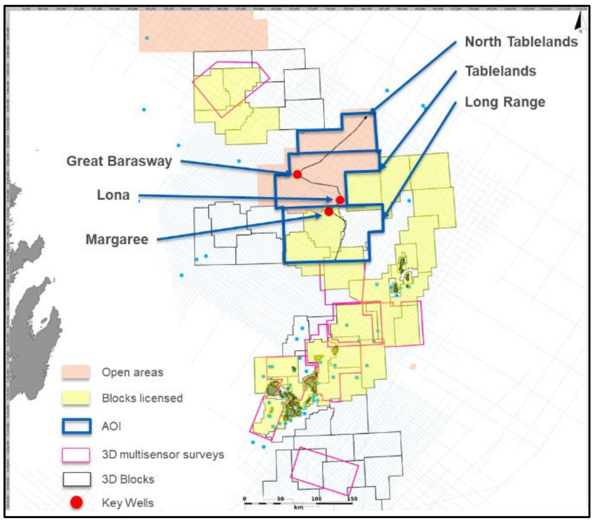

Figure 1: Regional map with the 3D multisensor seismic datasets (thin pink outlines) and the area of interest (AOI) in thick blue line over the Orphan and Flemish Basins

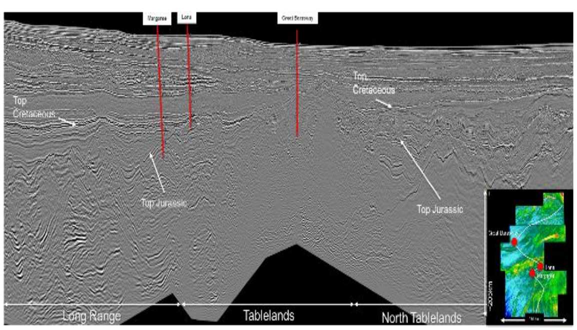

Figure 2: cross-section through Long Range, Tablelands and North Tablelands 3D surveys, with well ties for the Margaree, Lona and Great Barasway wells.

Brief rock physics review

All three wells were used to build a regional rock physics model (Figure 3) which takes into account the burial depth in addition to the elastic properties for the various lithologies present in the wells. The ellipses represent the results of stochastic forward modelling at specific depths (2250 m, 2750 m and 3000 m) based on the statistical variability of the rock properties, observed in the wells at various depths. At this step of the modelling various fluid scenarios were modelled, using fluid substitution to understand brine, oil and gas cases.

From the rock physics analysis, it can be observed that at all depths, the sands have a similar or higher acoustic impedance compared to the shales and lower Vp/Vs. The hydrocarbon sands (gas or oil) are characterized by a very low acoustic impedance and Vp/Vs compared to shale and porous limestone. The separation between the brine and the oil response is very weak irrespective of the depth. It will therefore represent a significant challenge, with even the highest quality seismic data, to be able to make the separation between the two fluids since there is such a substantial overlap in the measured rock properties.

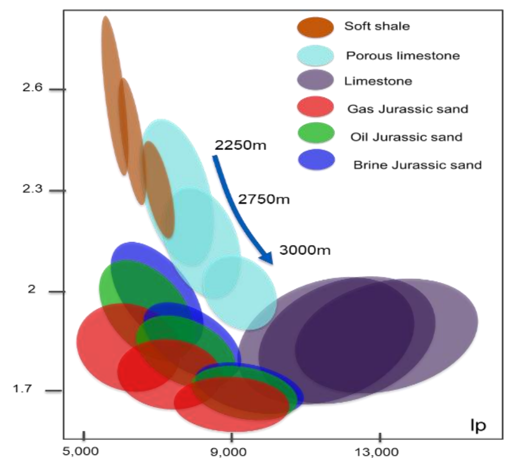

Figure 3: Depth dependent rock physics model for the 3 wells present in the study area.

Regional seismic imaging and AVA screening workflow

On the processing-imaging side, the whole area was processed with a broadband pre-stack time migration (PSTM) sequence based on the upgoing wavefield (a direct product of the multisensor streamer acquisition).
During the processing of the three surveys particular attention was paid post-migration to the quality of the pre-stack seismic data especially on: low frequency content preservation and enhancement, flatness of the gathers, multiple content, angle stacks decomposition (with up to 55 degree incidence angle of useable data), frequency harmonization between the angle stacks and the overall noise level.

Figure 4 shows the quality of the regional product at the Great Barasway well location that was used for AVA screening. The top reservoir can be clearly seen on the far angle stack and this was used for the interpretation, as it was easier to pick than on the full stack data.

To facilitate a more rapid assessment of the regional prospectivity potential of the entire area, an AVA screening workflow was implemented consisting of the estimation of the elastic properties (relative acoustic impedance, shear impedance and Vp/Vs) from the derivation of the intercept-gradient. The Shuey 3 term equation was used as higher angle of incidence are available. 5 angle stacks were used for the intercept-gradient estimation with the last angle range being from 45 to 55 degree.

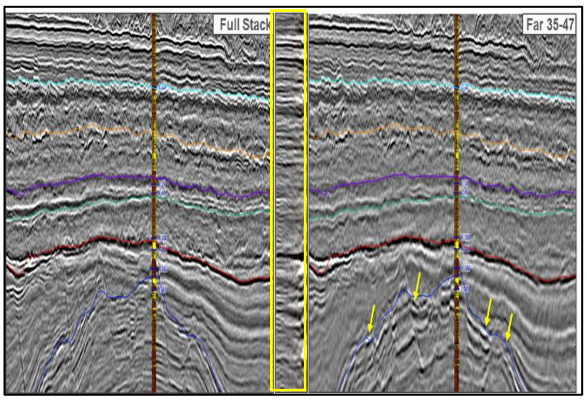

Figure 4: Cross-section through the Great Barasway well showing the value of the far angle stacks to identify and map the top Upper Jurassic reservoir and the PSTM gathers quality (yellow track). This reservoir is characterized by an increase of impedance (a bright white positive amplitude reflection) indicated by the yellow arrows.

This regional workflow allows the mapping of the relative Vp/Vs response at the Upper Jurassic level (Figure 5).

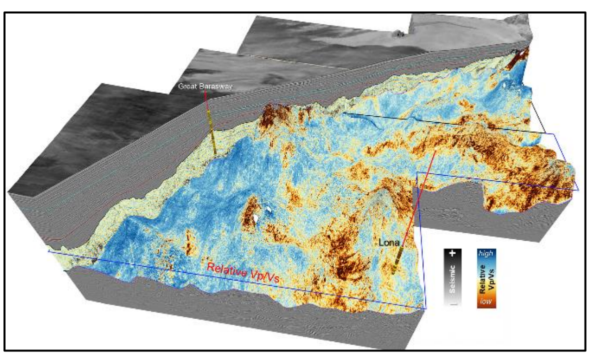

Figure 5: Example of extraction of the relative Vp/Vs over the PSTM Tablelands and North Tablelands, co-rendered with the amplitude data in seismic section. The 3D surface shows the amplitude of Jurassic sediments extracted from the Relative Vp/Vs attribute and projected on the Base Mesozoic surface showing Jurassic sand distribution as low Vp/Vs anomalies (orange-brown colors).

From this extraction, based on the regional seismic interpretation, some very clear channel features can be observed suggesting the presence of sands in the system and some potential prospective areas characterized by a very low relative Vp/Vs (the darker brown areas). These regional volumes would be a valuable tool to further derisk some key areas for license applications.

In-depth imaging and QI analysis

In addition to this regional time product, a more advanced depth imaging proof of concept (PoC) workflow of 500 km^2 was deployed around the Great Barasway well. This PoC included FWI, Kirchhoff depth migration (KPSDM) and a Least-Squares Migration (LSM) (Alcantara et al., 2020). LSM is designed to overcome the issues of illumination and frequency on the migrated image when there is a complex geology, or as a result of non-optimum acquisition parameters (Nemeth et al., 1999).

Full Waveform Inversion (FWI) could create higher-resolution velocity models than traditional reflection tomography. Its commercialization was concurrent with the routine use of broadband seismic. Both high-resolution FWI models and broadband seismic data can provide the low frequency model (LFM) for absolute elastic property generation, enabling well information to be a blind well control point, such that elastic attributes such as acoustic impedance and Vp/Vs ratios can be confidently predicted away from well locations (Feuilleaubois et al., 2017, Jones et al., 2018 and Reiser et al., 2019).

The starting frequency for the inversion was 4 Hz and was performed up to 25 Hz. This produced a high frequency velocity model enabling the detection of some small shallow geological features. The FWI velocity model was used for the low frequency model necessary for the pre-stack simultaneous inversion (Figure 6) but not all the higher frequencies were required as genuine low frequencies from the amplitude seismic can be used.
The elastic background model (acoustic, shear impedance and Vp/Vs) was performed using the shale background model derived from the rock physics analysis. It can be seen that the match at the well location, not used for the low frequency model building, matches very well to the well elastic logs despite the fact that all the estimations are based on the FWI compressional velocity.

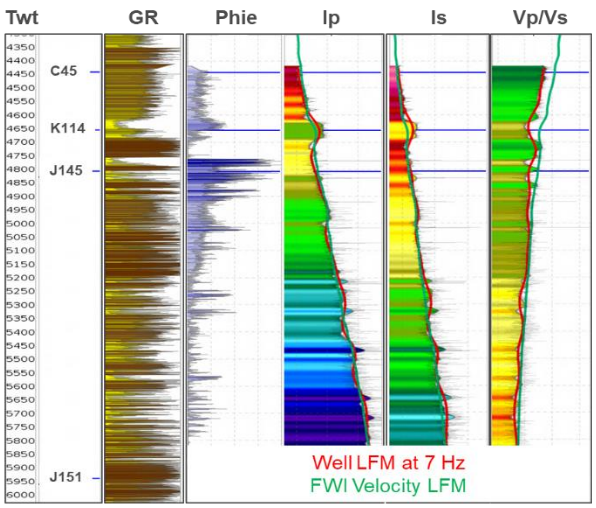

Figure 6: Cross-validation of the low frequency model at the Great Barasway well. The red curve corresponds to the band-limited well logs (acoustic, shear impedance and Vp/Vs filtered up to 7 Hz) and the green curve is the elastic prediction based on the FWI velocity model. The main interval of interest is the Upper Jurassic J-145 level, present in this well as a thin sand interval layer with good porosity (~30 %).

Relative Vp/Vs overlaid on the pre-stack seismic around the Great Barasway well (Figure 7) reveals some interesting AVO anomalies characterized by very low relative Vp/Vs values on the flank of the main structure. Based on the rock physics work, low relative Vp/Vs could indicate the presence of hydrocarbons. These flank anomalies are significantly lower in value compared to the low Vp/Vs "anomalies" penetrated by the Great Barasway well, suggesting the flank anomalies could be more likely to be hydrocarbon charged than at the well location. These anomalies are of reasonable size, and can be spatially tracked on the 3D (inset in Figure 7) and appear bounded by some well-imaged faults.

Conclusions

3D regional multisensor broadband seismic datasets acquired in the last three years in the Orphan Basin combined with rock physics analysis and pre-stack data inversion demonstrates the reliability of the data for pre-stack broadband AVA screening and prospectivity purposes, and refined for a detailed local appraisal of hydrocarbon potential.

This dataset shows further that based on the same input, the upgoing wavefield, the use of state-of-the-art depth imaging technologies can lead to better subsurface imaging and improved reservoir understanding.

The datasets and products discussed in this study, form a robust platform for a more thorough review, expected to provide an improved geological understanding of this under-explored basin offshore eastern Canada and significantly derisk additional opportunities.

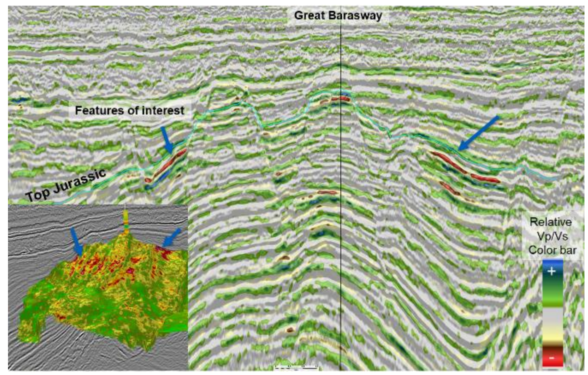

Figure 7: Relative Vp/Vs extraction along a random line going through the Great Barasway well. Note the low Vp/Vs anomalies of interest on the flanks of the structure that could be prospective (mapped spatially in the 3D visualization inset)

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