Reservoir Properties Estimation Using Broadband Seismic with No Calibration – A Case Study from the West of Shetlands

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SUMMARY

The main objective of this project was to evaluate the ability to estimate reservoir properties directly from broadband seismic without using well information for calibration. This estimation was achieved by using a combination of seismic velocity and pre-stack seismic inversion results. This was followed by a lithology-fluid classification in the pre-stack domain (acoustic impedance and Vp/Vs) and porosity estimation. The results are very encouraging and demonstrate the value of acquired broadband pre-stack data for identifying, delineating, and de-risking prospects and also for accurately characterising reservoirs properties without introducing prior pre-conceived reservoir models to bias the calculations.

Introduction

Estimating reliable absolute reservoir properties away from wells has always been a challenge for reservoir geoscientists, yet where it is possible the value of the information can be significant in de-risking a prospect. In addition, in appraisal/development and reservoir optimisation, any reliable elastic information extracted from seismic can assist in placing a well in the right location and in optimising the well trajectory.

Within a well, absolute properties can be measured from wireline data directly with kHz of information giving excellent vertical resolution. However, away from the well, seismic data has to be relied upon. The seismic is by nature band-limited (due to the seismic energy source and signal attenuation) and thus lacks the absolute values of direct measurements in the ground. Therefore, to gain the maximum amount of valuable information, seismic data with as broad a bandwidth as possible is required (rich on the low frequency side but not to the detriment of preserving the high frequencies) to provide the best vertical resolution at the reservoir level (ten Kroode *et al*., 2013). It is also important to fully exploit the AVO behaviour of the data throughout the extent of the pre-stack information and to know that from the near to the far offsets the amplitude and phase have been measured and preserved reliably over the full seismic bandwidth without any prior assumptions. With the introduction of dual-sensor towed streamer seismic technology (Tenghamn *et al*., 2007) the industry now has access to seismic data with a significantly broader range of low and high frequencies. The use of co-located vertical velocity and pressure sensors in the streamer allows for an accurate and robust removal of the receiver ghost effects using a local wavefield separation methodology. The advent of multi-component streamer technology has started a new era of broadband data in the marine seismic industry.

Using dual-sensor streamer technology has not only allowed towing the streamer deeper in a quieter recording environment but has significantly increased the amount of reliably measured low frequency information without compromising the high frequencies and the AVO/AVA information. These improvements have a tangible benefit for the whole workflow of quantitative seismic interpretation and structural seismic interpretation; from the low frequency model building to the elastic properties estimation and depth conversion through the pre-stack wavelet extraction.

In this paper we will be using a case study to demonstrate the value of high fidelity broadband seismic data for improved delineation, estimation of the reservoir properties and ultimate de-risking of a new prospect.

The area of interest

Since 2007, PGS has acquired numerous broadband seismic surveys (2D, 3D and baseline 4D) in many key basins around the world and in various geological settings. For this study a representative survey was chosen from the Faroe Shetland Basin acquired in 2012 in partnership with TGS.

The Faroe-Shetland Basin (FSB) is located offshore northwest Britain (Figure 1) and including the Rockall Basin, the Hatton Basin and the Hatton Continental Margin form the so-called Atlantic Margin bordering the United Kingdom. The water depth in this region is up to 2,000m and the sediment fill can be more than 5km thick. The Faroe-Shetland Basin is a Jurassic-Cretaceous-Paleocene rift basin and is the geological continuation of the faulted-block and graben province of the Møre Basin offshore Norway. Paleocene aged basaltic lava and hyaloclastite flows cover the majority of the basin impeding imaging and interpretations of the older sequences. Reservoir provenance and quality is a major source of uncertainty along this margin and there is a need for high quality seismic data to allow the best chance to properly image the geology and the trapping mechanisms for delineation of hydrocarbon accumulations beneath the volcanics.

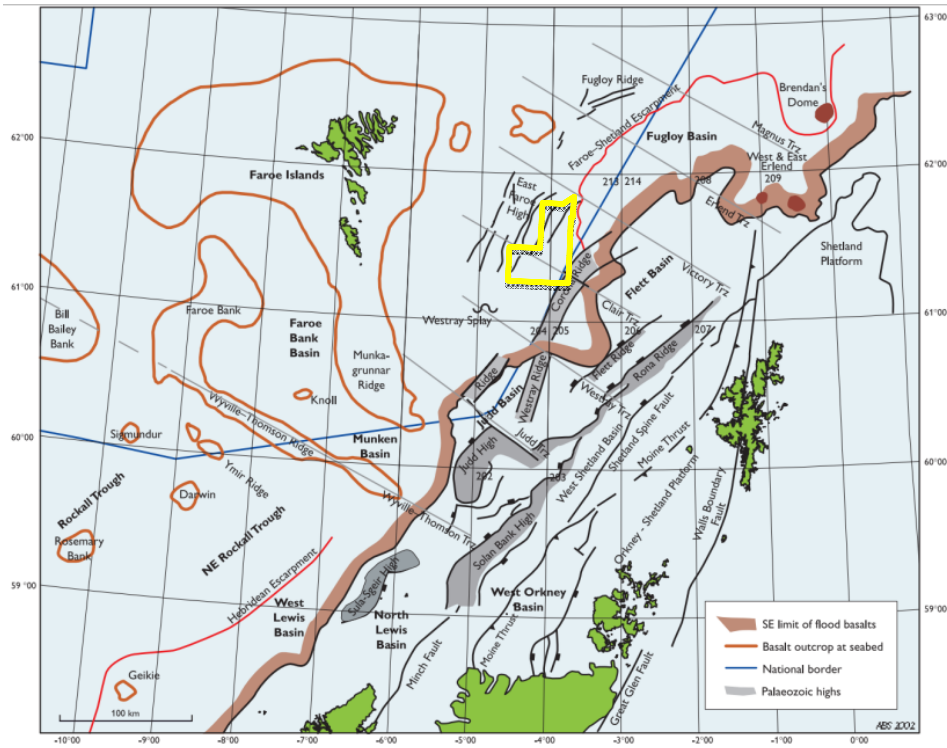

Figure 1 *Location map of the area of interest showing the main structural elements and the survey location (A. B. Sorensen., 2003).*

Workflow and main results

Most of the published examples of broadband seismic inversion to date have been focused on the computation of relative reservoir properties and have provided significant uplift in term of reservoir understanding. The objective here is to further investigate the high fidelity of acquired broadband seismic by deriving estimations of absolute elastic attributes and benchmarking the results against available blind wells data.

As the marine seismic used has a very broad bandwidth from 3Hz to 60-70Hz at the reservoir level, the goal in our study has been to invert the pre-stack seismic data for absolute elastic properties without using the available well information usually used for the low frequency model. Instead, the seismic velocities are multiplied by a constant density to get an impedance volume for the low frequency model.

Within this survey, there are a number of discoveries, including Tornado and Suilven, but also some recent dry wells, such as in the Onslow and Handcross prospects. None of these wells were used in the reservoir property estimation to constrain the low frequency model building or to constrain the seismic inversion process.

To gain insight into the reservoir properties (e.g. porosity), inversion for both acoustic and shear (P and S) impedances is required, which also allows the calculation of Vp/Vs ratio.. It is relatively simple and un-informative to have only an inversion for P-impedance, as this does not necessarily mean that the data is AVO compliant since a significant amount of manipulation can be applied to achieve an acceptable acoustic impedance inversion result. The real benefits come from using a simultaneous combination of both P-impedance and Vp/Vs ratio. The reliable estimation of both attributes indicates an AVO stability throughout the full pre-stack analysis. After performing the pre-stack simultaneous inversion, the 3D volumes can be characterised into lithologies and fluid classes (shale, sandstone, hydrocarbons and brine) using the P-impedance vs Vp/Vs cross-plot. The discrimination of the lithologies and fluids is performed using only simple polygons in the cross-plot domain (top left hand side of Figure 2).

A good match (*a posteriori*) between the seismically estimated lithology-fluid volume to the volume fractions from the well logs (Figure 2) can be observed across the random line going through the Tornado Field (left hand side) to the Suilven discovery (right hand side).

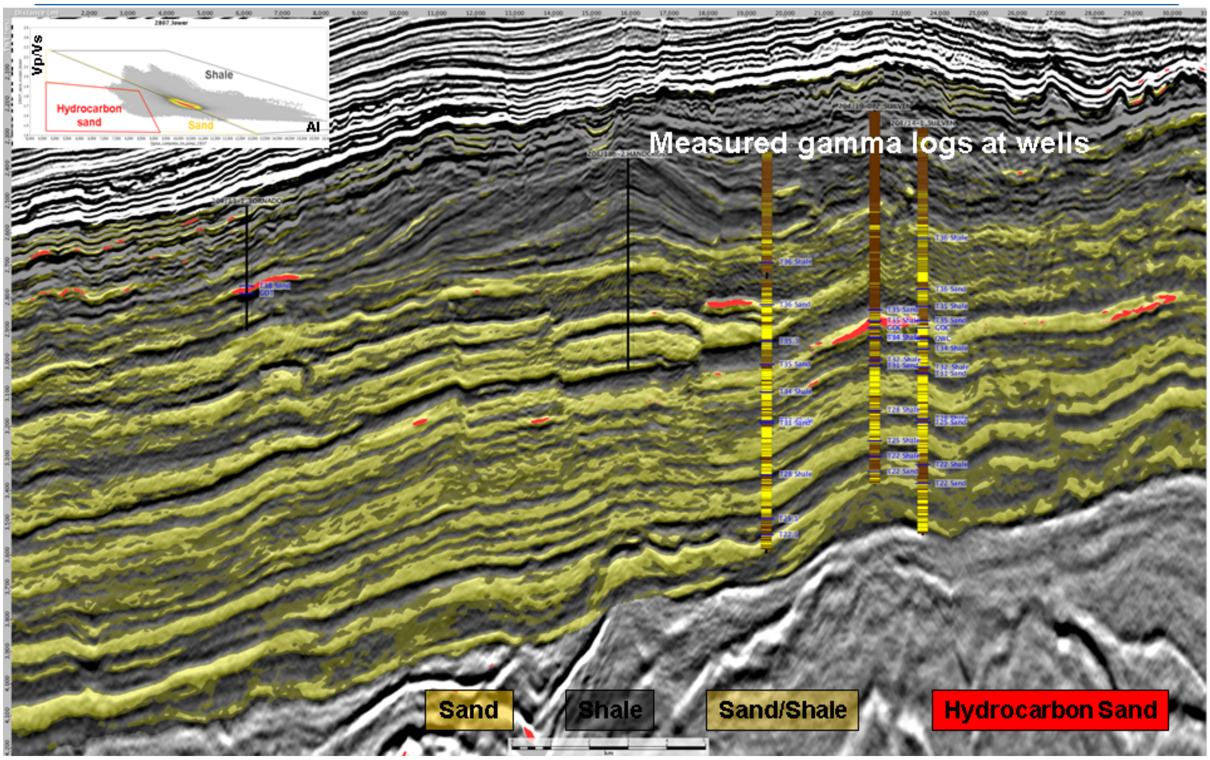

Figure 2 *An arbitrary line through the acquired broadband seismic data showing the lithology-fluid classification, based on the pre-stack inversion. The wells are displaying the measured gamma logs as a QC of the lithology classification.*

Once this robust prediction of sandstone and shale distribution has been established (without any direct/calibration well input), the relation between P-impedance to porosity in sandstones (established from the well) can be used to derive a 3D porosity volume (Figure 3). The relationship between acoustic impedance and the porosity is established at the well in the sandstone and can be applied directly to the estimated sandstone volume (and associated impedance) resulting from the pre-stack seismic inversion.

It can be observed that the match between the porosity from the well and the porosity estimated from the pre-stack seismic inversion followed by the lithology-fluid classification is in very good agreement even with no wells used for the calibration of the pre-stack simultaneous inversion.

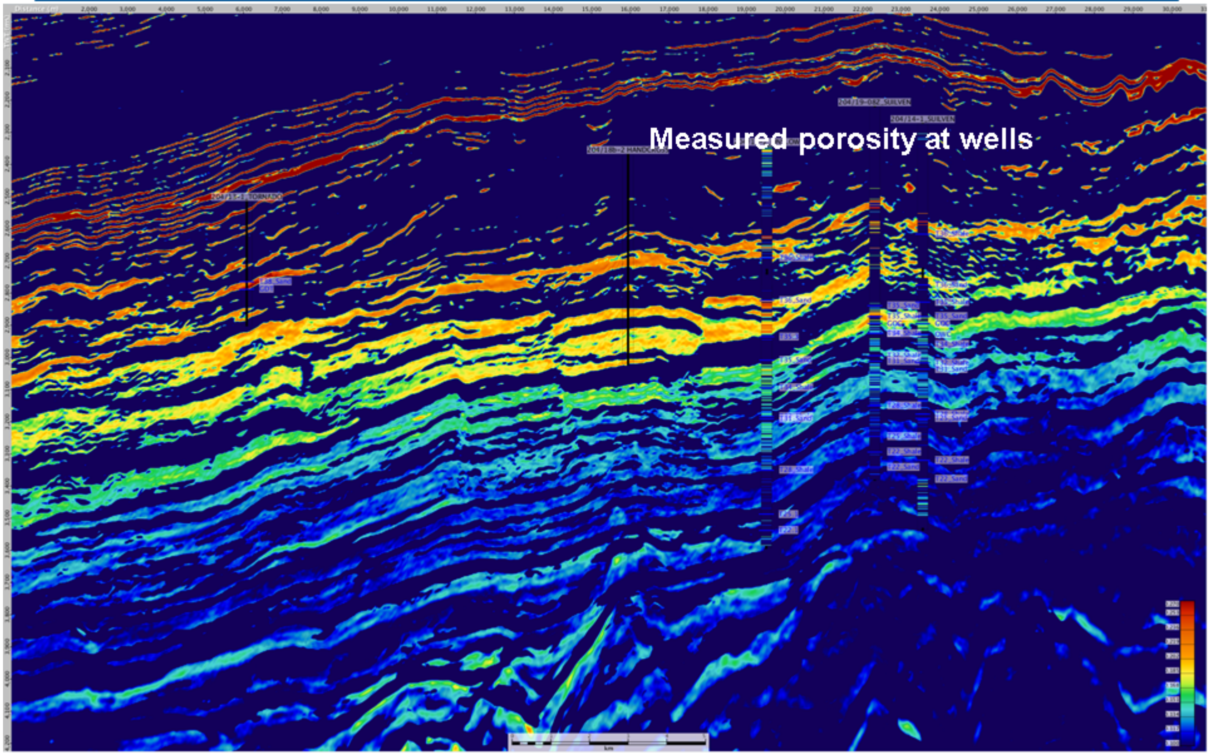

Figure 3 *An arbitrary line through the acquired broadband seismic data showing the estimated porosity, based on the pre-stack inversion. The wells are displaying the petrophysical porosity logs as a QC of the estimation.*

Summary

This paper exploits the full potential of the dual-sensor seismic data to predict lithology-fluid distribution and porosity. No well data is used for calibration of the seismic inversion process, and only basic assumptions about the rock physics of the area are made. Although the porosity estimation relies on the P-impedance, a reliable Vp/Vs volume is required for the sandstone and shale discrimination. This study underlines the advantages of deriving elastic and reservoir properties using all the pre-stack AVO information – where it is sufficiently robust and reliable. As a result of the broader seismic frequency bandwidth, this study also demonstrates that the dual-sensor seismic data can provide reliable estimation of these properties, without using well calibration in the process. This indicates that the workflow for dual-senor broadband data outlined above is a very valuable tool to assist in de-risking leads and prospects.

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References

Tenghamn, R., Vaage, S. and Borresen, C. [2007] A dual-sensor, towed marine streamer: its viable implementation and initial results. *77th SEG Annual Meeting Expanded Abstracts*, 989-993.

Sorensen, A.B. [2003] Cenozoic basin development and stratigraphy of the Faroes area. *Petroleum Geoscience,* **9**, 189-207.

ten Kroode, F., Bergler, S., Corsten, C., de Maag, J.W., Strijbos, F. and Tijhof, H. [2013] Broadband seismic data – the importance of the low frequencies. *Geophysics*, **78.2**, WA3-WA14.