Reservoir properties estimation from marine broadband seismic without a-priori well information: A powerful de-risking workflow

Cyrille Reiser, Matt Whaley and Tim Bird, PGS Reservoir Limited*

Summary

This paper presents a case study demonstrating the value of high fidelity pre-stack broadband seismic data for improved target delineation, estimation of reservoir properties and ultimately de-risking of a prospect or well positioning. Without using well data as input, predictions of reservoir properties from pre-stack seismic elastic attributes are made which prove to be robust and reliable when compared to log measurements from un-used ('blind') wells.

Introduction

Estimating reliable absolute reservoir properties away from limited and spatially-biased well control has always been a challenge for the industry in general and for reservoir geoscientists specifically. Yet, where it is possible to reliably estimate these reservoir properties, their value can be significant in de-risking a prospect or a new well location.

Equally importantly, in appraisal/development and reservoir optimization is reliable elastic information extracted from seismic data that can be linked to a rock physics analysis for key reservoir properties. Such seismic derived information can assist in placing a well in the right location and in optimising the management of a producing field.

Within a well, absolute properties can be measured from wireline data directly over a kHz range providing excellent vertical resolution. However, away from the well, seismic data has to be relied upon. Seismic data is, by nature, band-limited (due to the energy output by the source and the signal attenuation in the earth) 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 using pre-stack information and to know that from the near to the far offsets the amplitude and phase of the data have been measured and preserved reliably over the full seismic bandwidth.

The advent of multi-component streamer technology (Tenghamn et al., 2007) has started a new era of broadband data in the marine seismic industry, enabling the recording of seismic data with a much 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.

Using this technology has allowed towing the streamer deeper in a quieter recording environment (improving signal-to-noise and penetration), but more fundamentally it has increased the amount of reliably measured low frequency information while at the same time retaining all the high frequencies that the geology and depth allow, and preserving the AVO/AVA information across all offsets for elastic attributes estimation. 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 pre-stack wavelet estimation.

Study area

For this study a representative survey was chosen from the Faroe Shetland Basin (FSB), on the UK Atlantic margin.

The Faroe-Shetland Basin is a Jurassic-Cretaceous-Paleocene rift basin. A series of Paleocene-aged sandstones have been mapped on a regional scale as channel-fan complexes. The 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 reservoir sandstone distribution and hydrocarbon accumulations. In the study area the main reservoirs are within the Palaeocene Lamba and Vaila formations. The Tornado discovery (UK well 204/13-1) found a significant gas cap and underlying oil rim in an excellent quality sandstone reservoir in the T38 unit of the Lamba formation while the nearby Suilven field contains oil and gas in the older T35 units sandtones of the underlying Vaila formation. This is an area notoriously known for 'false positive' AVO anomalies.

DOI http://dx.doi.org/10.1190/segam2015-5897743.1

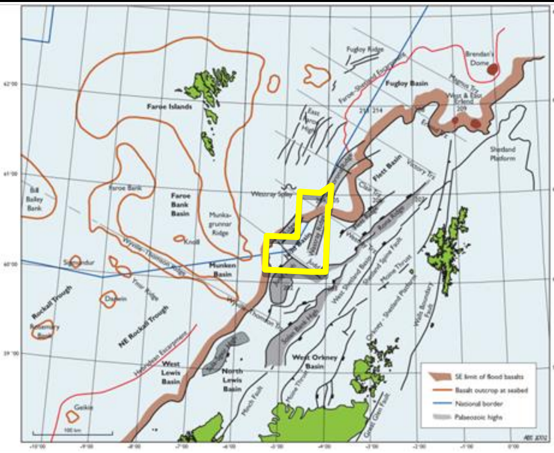

Figure 1 Location map of the area of interest showing the main structural elements and the survey location (A. B. Sorensen., 2003).

Workflow and main results

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

As the marine seismic data used here had a bandwidth from 3Hz to 60-70Hz at the reservoir level, the goal in our study has been to invert the pre-stack data for absolute elastic properties without using the available well information as calibration points. Traditionally this well information is used for building the low frequency model to fill in the missing frequencies on the low side of the amplitude spectra. The signal-to-noise (S/N) of this broadband measured across all offsets/angles is relatively high. The signal-to-noise has been estimated for all angle sub-stacks and compared to that derived for the legacy conventional data. A minimum improvement in S/N of 200% is observed, with the greatest uplift occurring at the highest and lowest ends of the spectrum, and an overall improvement across all frequencies and offsets/stacks is noted.

In this case study the seismic velocities are multiplied by a constant density to get an estimated impedance low frequency model.

Within this survey, there are a number of discoveries, including the Tornado and Suilven fields, but also some recent dry wells. None of these wells were used to constrain either the low frequency model building or the seismic inversion process or the lithology-fluid prediction.

To gain insight into the reservoir properties (e.g. porosity), inversion for both acoustic impedance and Vp/Vs ratio is required. It is less informative to have only an inversion for P-impedance as in most cases this does not separate lithology and fluid effects. The real benefits come from using a simultaneous combination of both P-impedance and Vp/Vs ratio through a pre-stack seismic inversion. The reliable estimation of both attributes indicates an AVO/AVA stability throughout the full pre-stack domain. After performing the seismic inversion, the 3D volumes can be characterized lithologies lithology and fluid classes (shale, sandstone, hydrocarbon filled sandtones and brine sandtones) using the P-impedance versus Vp/Vs cross-plot. In this case study, the discrimination of the lithology and fluids is performed using only simple polygons in the cross-plot domain (top left hand side of Figure 2). More sophisticated classification, such as Bayesian classification could have been presented but to demonstrate the robustness of the workflow a simple polygon-based classification was deemed appropriate.

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 through the Tornado Field (red feature on left-hand side) to the Suilven discovery (right-hand side).

Once this robust prediction of the sandstone and shale distribution has been established (without any direct calibration using well log input), the relation between P-impedance to porosity in the sandstone (established from the wells) can be used to derive a 3D porosity volume (Figure 3). The relationship between acoustic impedance and the porosity is only established at the wells within the sandstone intervals and is applied directly to the estimated sandstone volume (and associated acoustic 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 excellent even though the wells have not been used for the calibration of the pre-stack simultaneous inversion.

DOI http://dx.doi.org/10.1190/segam2015-5897743.1

Conclusions

This study aimed to exploit the full potential of the dual-sensor towed streamer seismic data to predict lithology-fluid distribution and porosity through a robust quantitative interpretation workflow. No well data was used directly for the calibration of the seismic inversion process, and only basic assumptions about the rock physics of the area were made. Although the porosity estimation within the sand intervals relies on the relationships between P-impedance and porosity, a reliable Vp/Vs volume is required for the sandstone and shale discrimination. P-impedance is not enough. The close agreement between seismically-predicted reservoir properties and the blind wells in this study underlines the advantages of deriving elastic and reservoir properties using all the broadband pre-stack AVO information. This study demonstrates that, as a result of the broader seismic frequency bandwidth, this type of seismic data has the pre-stack robustness and fidelity to provide reliable estimation of these properties, without using well calibration in the process.

The implication is that the workflow outlined above is a very valuable tool to assist in de-risking leads and prospects and that the same workflow can be used by reservoir geoscientists and engineers to better characterize their reservoirs away from limited well control.

Acknowledgments

The authors thank PGS and TGS for granting access to this marine seismic dataset and for permission to publish this work as well as many contributors within PGS.

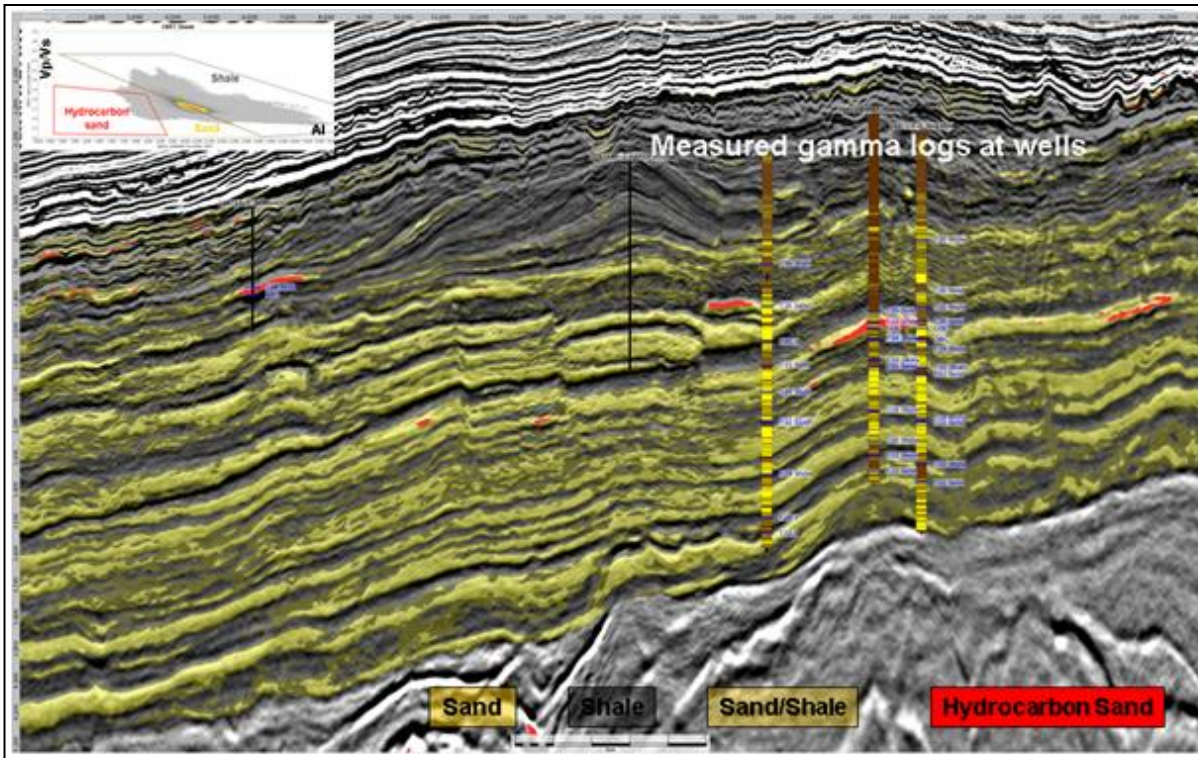

Figure 2 An arbitrary line through the acquired broadband seismic data showing the lithology-fluid classification, based on the pre-stack inversion. The wells are displaying the measured gamma logs as a blind QC of the lithology classification.

DOI http://dx.doi.org/10.1190/segam2015-5897743.1

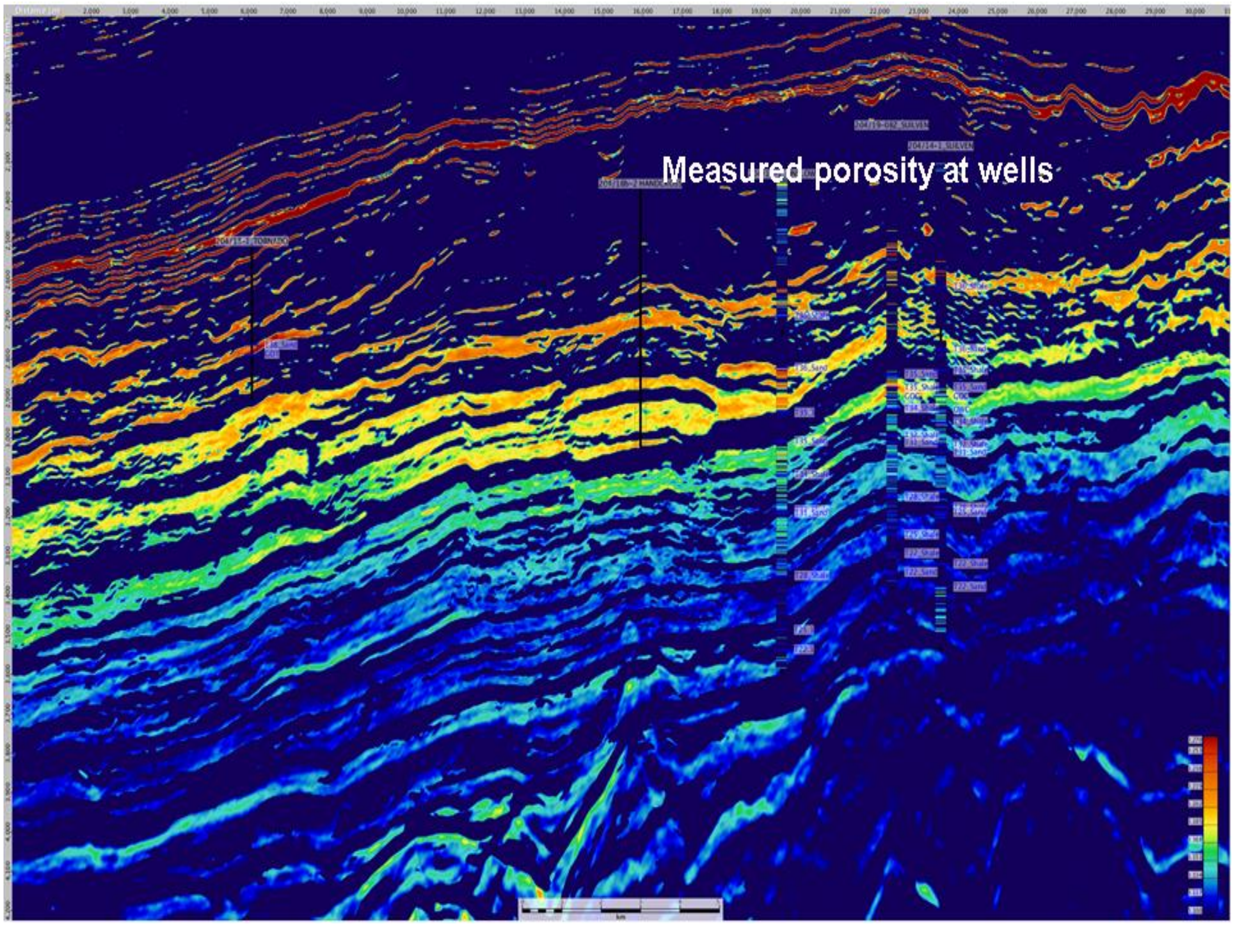

Figure 3 An arbitrary line through the acquired broadband seismic data showing the estimated porosity, based on the pre-stack inversion. The well columns display the petrophysical porosity logs as a QC of the estimation.

DOI http://dx.doi.org/10.1190/segam2015-5897743.1

EDITED REFERENCES

Note: This reference list is a copyedited version of the reference list submitted by the author. Reference lists for the 2015 SEG Technical Program Expanded Abstracts have been copyedited so that references provided with the online metadata for each paper will achieve a high degree of linking to cited sources that appear on the Web.

REFERENCES

Sorensen, A. B., 2003, Cenozoic basin development and stratigraphy of the Faroes area: Petroleum Geoscience, **9**, no. 3, 189–207. http://dx.doi.org/10.1144/1354-079302-508.

ten Kroode, F., S. Bergler, C. Corsten, J. W. de Maag, F. Strijbos, and H. Tijhof, 2013, Broadband seismic data — The importance of the low frequencies: Geophysics, **78**, no. 2, WA3–WA14. http://dx.doi.org/10.1190/geo2012-0294.1.

Tenghamn, R., S. Vaage, and C. Borresen, 2007, A dual-sensor, towed marine streamer: Its viable implementation and initial results: 77th Annual International Meeting, SEG, Expanded Abstracts, 989–993. http://dx.doi.org/10.1190/1.2792571.