Rock Property Estimation Using Dual-Sensor Streamer Data without Well Constraint - North Sea Jurassic Case Study

M. Whaley* (PGS), E. Anderson (PGS) & C. Reiser (PGS)

SUMMARY

Broadband seismic data are becoming increasingly common, with many different methods of producing a broader range of frequencies. Accurately recorded broadband frequencies are of particular use for quantitative interpretation, and can give much improved seismic inversion results (Reiser et al., 2012). In this case study, dual-sensor streamer seismic data is compared with conventional seismic data over Grevling, a Jurassic oil discovery in the Central North Sea. The results of rock property estimation are compared by using an entirely seismic data-driven inversion workflow, i.e. without using any well information as input. The comparison between the two datasets demonstrates that there is highly valuable rock property information in the additional recorded frequencies of the dual-sensor seismic data, in particular the octave gain on the low frequency side at the reservoir level. The dual-sensor seismic data allows a better fluid discrimination within the reservoir and demonstrates a clear trend in the Vp/Vs data directly recorded by the seismic data. The workflow has been validated by comparing the seismic rock properties to an independently derived rock physics model and found to match closely.

Introduction

There are many potential benefits of broadband data, from increased resolution to improved inversion results (Carlson et al., 2007; Kelly et al., 2009; and Özdemir, 2009). However, it is important to understand the information that is contained in the extra bandwidth. Accurately recorded low frequencies have the potential to change the way seismic data can be used in exploration settings, allowing new workflows such as described by Lafet et al. (2012), and detailed below.

Dual-sensor seismic data can provide low frequency content down to 2.5Hz (Reiser et al. 2012), depending on the geological setting and acquisition environment. For an absolute inversion, the full range of frequencies down to 0Hz is necessary. Conventionally, the seismic velocity provides the lowest frequencies (0-4Hz) and kriged well information fills the gap to the seismic bandwidth (see Figures 1a and 1b). Whilst this gap is only a few hertz, it represents at least one octave, which has a significant impact on the seismic inversion. With lower seismic frequencies being accurately recorded by the dual-sensor streamer, the seismic bandwidth overlaps with the seismic velocity bandwidth, closing this gap and allowing rock property estimation without using any well data.

Accurately recorded low frequencies should mean that broadband data will produce a better estimate of rock properties than conventionally acquired data, and the workflow described below allows a data-driven comparison. A case study was chosen based on a 2010 PGS 3D survey over the Maureen field and Grevling discovery (UK Quad 16, Norwegian Quad 15 respectively). Grevling was chosen as a case study as it is a Jurassic oil reservoir, below a thick high impedance Cretaceous chalk section and in relatively shallow water – challenges common in North Sea exploration. The conventional dataset was acquired in 2005, but reprocessed in 2012 with a full modern processing workflow, so a fair comparison can be made in terms of data quality and processing. Extracts from the two surveys are shown below (Figure 2), decomposed into octave frequency bands, to demonstrate the quality and relative signal strength of the different parts of the amplitude spectra (Figure 1c).

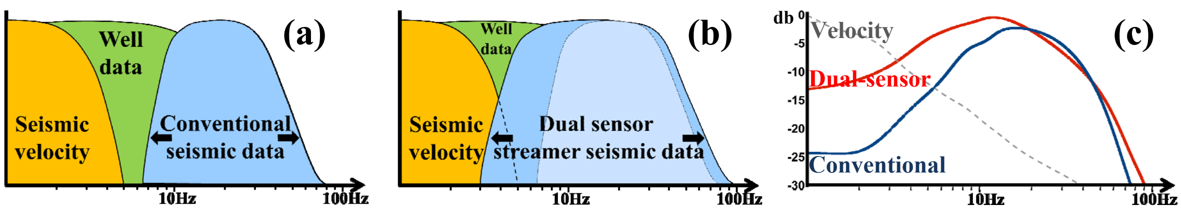

Figure 1 (a) and (b): schematic relationship of seismic velocity, well low frequency model and seismic bandwidth for conventional and dual-sensor seismic data, respectively. (c): observed seismic and seismic velocity bandwidth at the reservoir level (using log frequency scale).

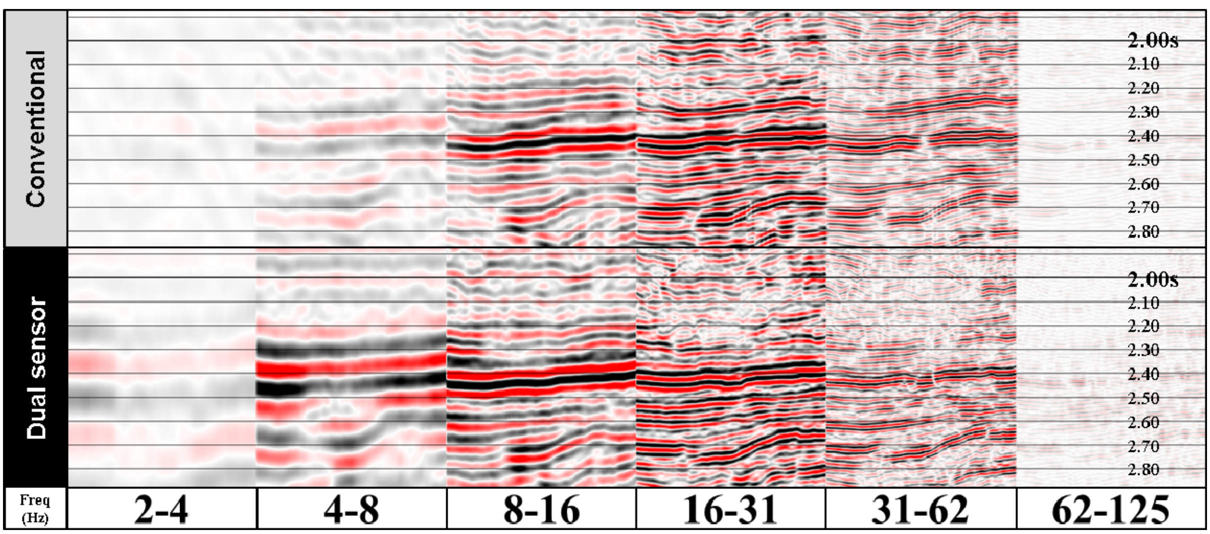

***Figure 2** Frequency panels for conventional and dual-sensor surveys decomposed from the seismic stack by stationary wavelet transform demonstrate the octave of difference in low frequency content.*

Theory

The dual-sensor streamer acquisition method uses co-located pressure and velocity sensors to allow the recording and separation of the upgoing and downgoing wavefields. This wavefield measurement allows the removal of the receiver ghost (Tenghamn et al., 2007). Further advances have been made recently to also remove the source ghost (Parkes et al., 2011), but this technology will not be addressed here. With the dual-sensor acquisition system, a broader range of frequencies can be recorded and the streamer can be towed deeper, significantly reducing the noise from the sea surface. The broader frequency input for inversion allows greater stability, resolution, and should improve the accuracy of rock properties estimated from seismic data.

For inversion and rock property estimation, the low frequency content defines the trends and allows the estimation of absolute elastic and rock property values. If these broad amplitude spectra are truly recorded amplitudes then the additional frequencies should offer improved rock property information and remove the need for reliance on well information, which is often variable in quality and poorly sampled spatially. In some cases the seismic inversion can be biased (Özdemir, 2009) and becomes more driven by the well and model than the measured seismic data.

Method

A relative pre-stack inversion was carried out to produce volumes of acoustic impedance **(**I_p) and shear impedance (I_s). A low frequency model is then required to reintroduce the frequencies not recorded by the seismic acquisition. Normally, this model incorporates a combination of well data (measured P-wave velocity [V_p], shear-wave velocity [V_s] and density) and the seismic velocity, however in this case just the seismic velocity and a density term were used. Depending on the data available a depth dependent density trend could be produced for the area and applied to the model, or otherwise a constant can be applied. In this study a constant density value was used to simulate an exploration setting with no well control. Even though this is an approximation, using a constant density (or simple trend) allows a first-pass estimation of absolute rock properties representing a significant improvement compared with a relative impedance estimation.

For this case study, a rock physics model was developed from the available well data and used as an independent comparison for the seismic derived rock property estimation. Well logs were interpreted to derive statistical depth dependent lithology trends (see Figure 3). These rock property trends, based on the end-member picks, were then used to produce probability distribution functions for the different lithology-fluid combinations. The model produced can then be used to determine whether the seismic elastic properties estimation matches the well data.

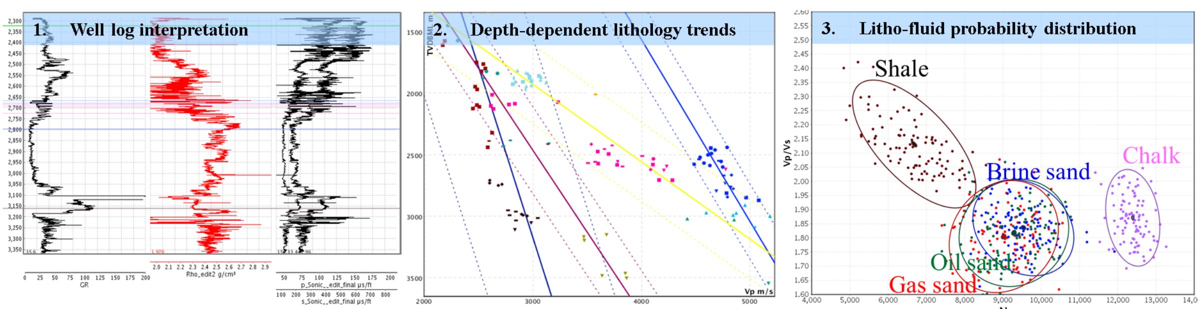

Figure 3 *Rock physics model workflow: interpretation of well logs allows modelling of trends and probabilistic distributions of lithology-fluids, in* I_p *vs* V_p/V_s *domain.*

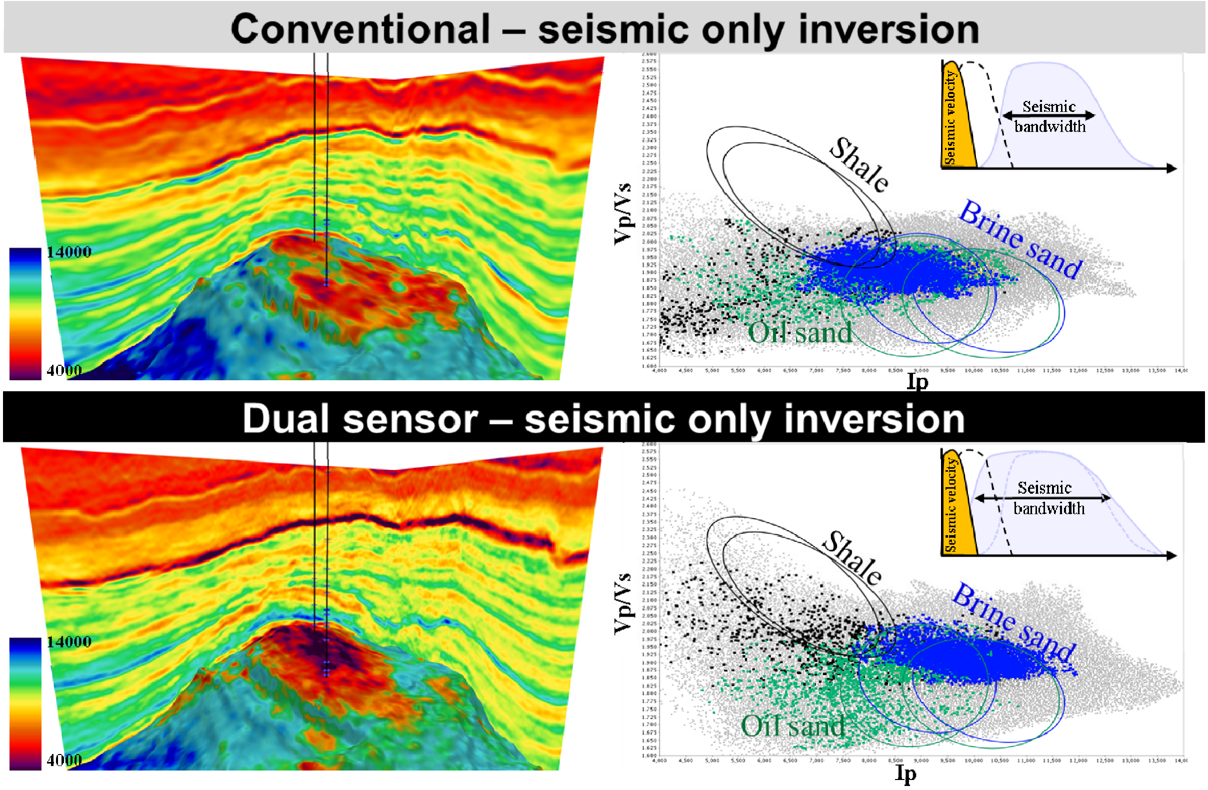

Figure 4 *Comparison of conventional and dual-sensor derived properties. Left: acoustic impedance estimated without any well data. Right: crossplots with data highlighted with coloured points determined by the top reservoir and oil-water contact (OWC) from the well data. The grey points show the scatter of all values within a cube of data around the reservoir. The coloured ellipses show the predicted response from independent well model for two depths covering the reservoir interval.*

Case study: absolute rock property estimation with conventional and broadband data, both using zero well input to the low frequency model (only seismic velocities)

The 3D images on the left of Figure 4 demonstrate the response of absolute P-impedance from a seismic inversion using no well data. The dual-sensor streamer data is more stable and discriminates the reservoir outline very well over the structure. Where the workflow has a potential weakness is in recovering large density variations, such as a thick hard chalk unit towards the top of the section, which should be characterised by a hard (blue) impedance response. This lack of response is due to the simple density approximation – a density model based on well data would introduce the large density variations needed to accurately estimate the chalk properties. However, at the zone of interest and in the reservoir interval, the seismic inversion matches the reservoir extent relatively well.

The crossplots on the right of Figure 4 show the rock properties extracted from the inversion volumes based on polygons picked using the well information to accurately map the top reservoir, OWC and extent of brine sand recorded in the wells. The dual-sensor streamer seismic inversion demonstrates several improvements: better fit to the predicted rock physics model (the coloured ellipses at two depths), a trend in the data not introduced by well data and significantly better discrimination between the brine and oil sand. Although the same constant was added to the V_p/V_s for both datasets, the dual-sensor data has a clear V_p/V_s trend recorded in the low frequency of the seismic data, whereas the conventional data mainly shows variation about the constant value.

An important note to make is that the rock physics model was independently derived and was not used in any way to constrain the seismic inversion. The properties do not match perfectly, as one would not expect from this relatively simple workflow, but certainly highlights the strength and contribution of the low frequencies in the dual-sensor data.

Conclusions

It has been observed that in this case study, the dual-sensor data has a full octave more of low frequency content at the reservoir level (Figure 2) representing significant value for the seismic inversion and the derivation of the elastic properties. This additional bandwidth allows good rock property estimation without using any well information. The comparison with conventional data demonstrates that the low frequency content significantly improves the value of the data for assessing lithology and fluid variation across a field and/or prospect. The dual-sensor streamer seismic data allows discrimination between the oil and brine sands within the reservoir and reveals a low frequency trend in the rock properties, matching the independently derived rock physics analysis.

The workflow used here to estimate rock properties without well data allows a useful comparison between the two seismic volumes. The variables are limited, with no well-driven wavelets, using a seismic velocity low frequency model and therefore completely seismic data-driven. The workflow may be further improved, for example, by building a more complex low frequency model using all available well information. However, the low frequency extension provided by this acquisition system will significantly reduce the dependence on well input to constrain the low frequency model, making the seismic an even more powerful elastic properties predictor than before.

This case study demonstrates the power of dual-sensor broadband data in several ways. Firstly, new workflows become possible, such as rock property estimation in an exploration setting. Secondly, the information gained from the extra low frequency content is shown to be of high value – a clear trend in the V_p/V_s values has been measured by the broadband data and not in conventional data.

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