



# Seismic Reservoir Characterisation Using a Long Offset Simultaneous Elastic Inversion. A Case Study: the Gryphon field, UK, North Sea

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## Summary

The work presented in this paper consists of a 3-D long offset pre-stack simultaneous inversion study on the Gryphon Field, North Sea. The injected sands reservoir in the Balder formation represents the main reservoir of this field. The use of higher angles should provide better understanding of the reservoir in terms of fluid distribution in the Balder and in the injected sands of the Frigg formations. The aim was to recover the density information from the long-offset seismic as well as the common elastic attributes such as the P-Impedance, Rho-Lambda and the Vp/Vs. The data pre-conditioning sequence and the use of a long offset dataset was found mandatory to achieve an optimum imaging of the reservoir and to estimate the density. This important pre-conditioning significantly improves the imaging, detection of the injected sands, and also increase the signal-to-noise ratio of the various angle stacks used for the simultaneous inversion. Inversion of 8 angle stacks with angle up to 58° degrees was carried out. The use of higher angles provides better understanding of the reservoir in terms of fluid distribution in the balder formation and in the injected sands of the Frigg formation

Here, we review the most favourable seismic data pre-conditioning for a reliable simultaneous long-offset inversion process and present the main results achieved in term of elastic attributes and density estimation.

## Introduction

For a decade or so acoustic and elastic impedance (Connolly, 1999) has become the regular tool in seismic reservoir characterisation to access the porosity and lithological information. At the same time there is a trend towards acquiring long offset data, in order to enhance the seismic reservoir characterisation by providing more AVO information. The use of higher angles should provide better understanding of the reservoir in terms of fluid distribution and AVO response. In the North Sea, the Tertiary reservoir for example is a very suitable target for a long-offset acquisition as the reservoirs are relatively shallow. Kerr McGee and their partners acquired a long-offset/high angle

streamer seismic in 2002. The cable length was sufficient (6000m) to allow angle of incidence of up to 58 degrees at the target. The Gryphon field is located in Block 9/18b, 320km northeast of Aberdeen, U.K. (Figure 1). The reservoir is a turbiditic channels system of the Tertiary (Eocene/Palaeocene) on production since 1994. Due to compaction and dewatering some Balder injected sands are present in the Frigg formation. In the area of the study, there are two fluid contacts: an oil-water contact and a gas-oil contact.

The main challenge of this reservoir characterisation is firstly to optimise the data pre-conditioning sequence for the long offset simultaneous

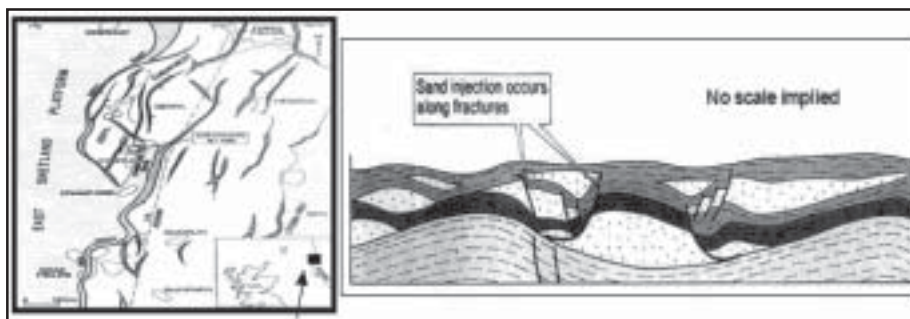


Fig. 1: The Gryphon Field, location map and geological description (After Newman et al., The Geology of the Gryphon Field, Petroleum Geology of Northwest Europe, Vol. 1, The Geological Society, London, 1993)

inversion process and secondly to demonstrate the use of large angle seismic for the extraction, by inversion, of the 3 parameters of the AVA equation ( $V_p$ ,  $V_s$  and  $\rho$ ). Beydoun et al (2003) presented the importance of the seismic inversion in the exploration and production context but highlighted the need for an optimal seismic data pre-conditioning prior to the inversion process. Helgesen et al (2004), and Hoerber et al (2004) demonstrated as well the importance of data pre-conditioning for seismic reservoir characterisation and/or AVO inversion. They focus on several aspects of the seismic processing workflow, starting from the wavelet estimation through time misalignment and residual move-out. This data preconditioning is even more critical when using long offsets, where basic assumptions in the inversion scheme could otherwise be violated.

This paper reviews the main steps of the seismic data pre-conditioning and the results of the simultaneous inversion on the long-offset Gryphon dataset.

## Data pre-conditioning prior to the Long Offset Simultaneous Inversion.

### Angle stack computation and spectral harmonisation:

Prior to the generation of the angle stacks a detailed AVO modelling has been carried out for the well using measured dipole sonic (Figure 2). It is then compared to the real migrated offset gathers at the well location in order to assess the match between the synthetic and the real data. Following this, a series of 9 narrow angle stacks (3 to 5

degree range) is computed from the PSTM gather dataset. Each pair was then used as input for the computation of a common part using the Common Seismic cube concept (explanation hereafter).

## Common seismic cube by automatic factorial Co-Kriging in the frequency domain

With this concept introduced by Coleou 2002, we make use of the redundancy of information between two consecutive angle stacks to compute a common seismic cube. A 3D common seismic is constructed using 2D factorial co-kriging operator in the frequency domain from variogram and cross-variogram of each frequency slice. This common seismic cube is considered as an intermediate angle stack (Figure 3). It shows an improved signal to noise ratio as well as better lateral continuity, especially at high frequencies. This process works as an efficient noise attenuator and destriper.

### Spectral harmonisation and wavelet estimation.

In order to obtain the maximum resolution for the discrimination of the reservoir, a spectral harmonisation between the various common cubes was carried out. The Spectral harmonisation was performed on each consecutive stack, using the lower angle stack as the reference. It can be seen that a good spectral harmonisation is obtained and the signal to noise ratio is preserved in this process. No noise was added to the far angle stacks even whitened to a near angle stacks. Following this step, wavelet estimation was

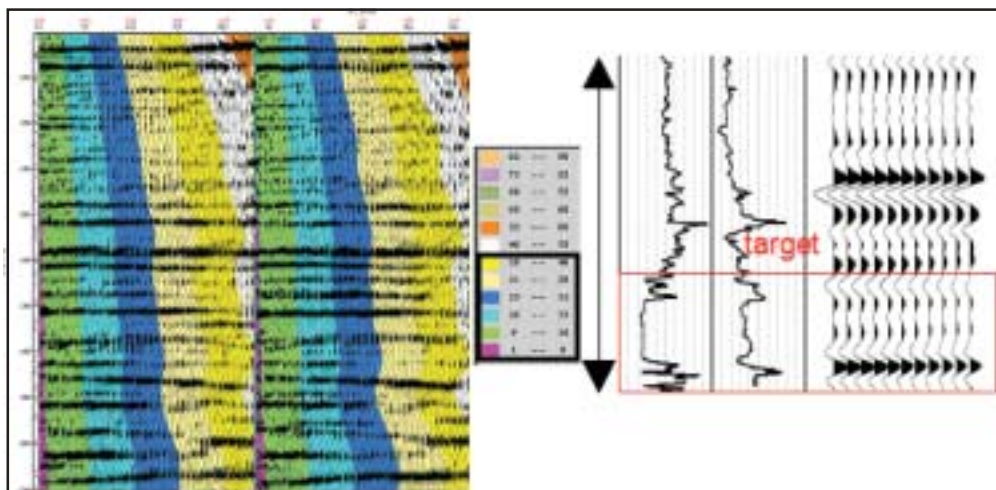
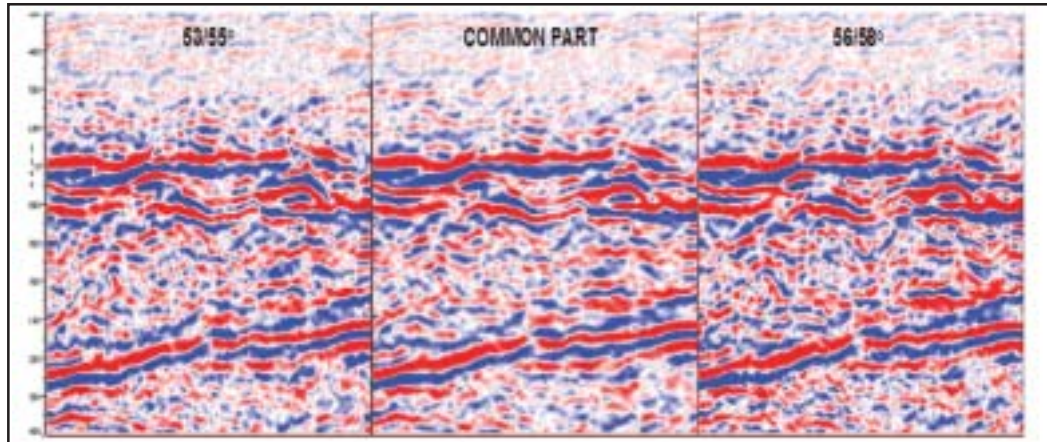


Fig. 2: Presentation of the AVO modelling in comparison with the real migrated gather at the well location with the angle of incidence overlay. This type of QC illustrates the accuracy of the processing as well as the well modelling.



**Fig.3.** Example of a common seismic cube computed from the angle stacks  $53^{\circ}$ - $55^{\circ}$  and  $56^{\circ}$ - $58^{\circ}$  on the long-offset dataset. We can observe the improvement in term of lateral continuity as well as the Noise reduction

carried out on the well with measured dipole sonic. The matching technique is based on a statistical approach that makes use of the spectral coherence, which allows an evaluation of the goodness of the fit and measures of the accuracy coherence (Walden et al, 1984). The wavelet estimation is carried out and validated for all the wells.

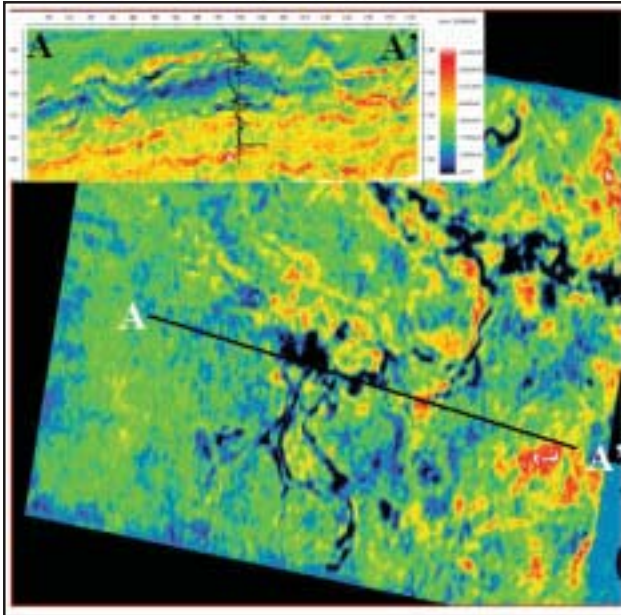
### True 3D Simultaneous Inversion scheme

CGG new 3D multi-cube simultaneous inversion engine scheme starts from an initial layered impedance model defined in the time domain created, in this case, by using ordinary co-kriging (log as hard data and migration velocity cube as soft data). This initial model building is carried out in the  $V_p$ ,  $V_s$  and density domain using a stratigraphic grid framework. During the inversion the initial model is iteratively modified using a simulated annealing scheme to find a global solution that optimises simultaneously the match between all the input angle stacks and their computed synthetics counterpart, calculated by convolution with full Zoeppritz reflectivity equations. This unique stratigraphic inversion scheme invert independently and simultaneously  $V_p$ ,  $V_s$  and density but also the two-way time of the microlayer to account for small discrepancy of the initial model in order to match the inversion model to the real data. This is extremely useful not only for 3D seismic but also for time lapse seismic where we could map the delta-time between the base and the monitor at the reservoir (Lafet et al, 2005). If the input seismic does not provide sufficient quality and angles to obtain three independent elastic parameters, then correlations between on or several parameters (typically a Gardner relation between density and velocity) can be introduced to constrain

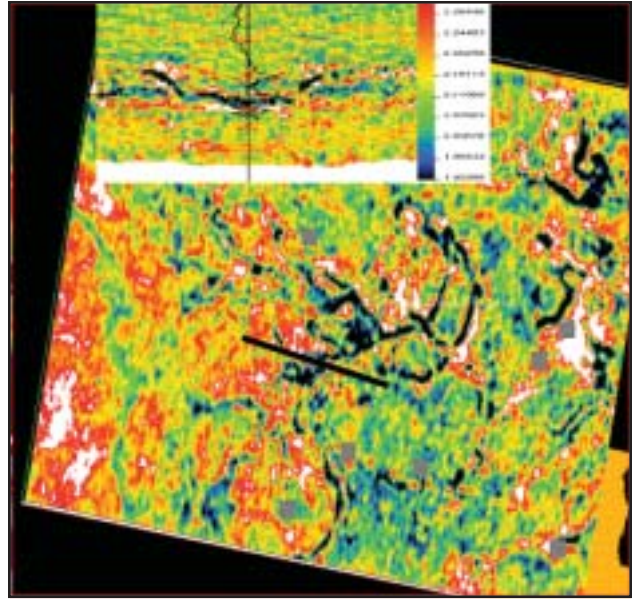
the inversion. In the present case, we were able to obtain a 3-parameter inversion, including density estimates that match the well logs. Critical to this success was: i) the use of good quality long offset data, giving access to large angles of incidence and higher-order AVO information; ii) Great care in the data pre-conditioning; iii) the use of a simultaneous inversion scheme based on the full Zoeppritz modelling, thus allowing large-angle data to be correctly inverted.

### Results and conclusions

This study illustrates the benefit of combining a detailed seismic data pre-conditioning with a powerful 3D stratigraphic simultaneous inversion scheme to yield an accurate mapping of the oil-filled injected sands oil-filled. Based on the use of a long-offset, we were able to estimate even the density. The data preconditioning has maximized the resolution and the signal/noise of the seismic, thus enabling us to generate 8 very narrow angle stacks up to 58 degrees. The tie between the simultaneous inversion results and the well is excellent. Stratigraphic simultaneous inversion has provided a consistent geological model that show good match with the Elastic logs for the long offset data. The elastic parameters, especially the  $Rho\lambda$  (Figure 4) and density (Figure 5) derived from this long-offset simultaneous inversion results illustrate interesting geological features that have provided improved understanding of the reservoir and the fluid distribution. In addition, it appears from the analysis of each inversion layer that all the elastic attributes ( $V_p/V_s$  ratio,  $Rho\lambda$  and density) yield coherent information about the rock properties, and are helping to discriminate the reservoir rocks within the field area.



**Fig. 4:** Example of the RhoLambda attribute on the stratigraphic layer 41 from the simultaneous inversion and one line through the well. The low RhoLambda values are in dark blue and characterise the main reservoir.



**Fig. 5:** Example of the Density attributes on the stratigraphic layer 49 from the simultaneous inversion. On the left corner an Inline through illustrates an injection sand feature highlighted in dark blue

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