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Highly Detailed Reservoir Imaging by Using Sparse Layer Inversion in a Complex N.Sea Turbidite

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SUMMARY

Sparse layer inversion (SLI), like sparse spike inversion (SSI), invokes a sparse reflectivity solution for the reconstruction of noisy seismic traces in the presence of a known, band-limited wavelet. However, solving for layers, i.e. dipoles, rather than individual interfaces, holds the potential for achieving increased detail and lateral stability over that usually achieved with SSI. In this paper, we present the method and show the application of SLI to a complex turbidite reservoir in the UK Central North Sea.

Introduction

When inverting the seismic convolution model to estimate broadband reflectivity, a sparse representation of the number of interfaces is a common choice. Sparseness leads to increased temporal detail and sharp interface definition. However, given the performance of such sparse spike inversion (SSI) methods with regard to noise and layer continuity, an alternative means for achieving bandwidth extension is worth considering. In this paper we discuss sparse layer inversion (SLI) (Zhang and Castagna, 2011; Zhang et al., 2013), which aims to resolve subtle seismic events below tuning thickness. This method was applied to seismic data from a Paleocene discovery in the UK Central North Sea, focusing on the complex thin bed interference pattern affecting the Mey sandstone reservoir. The objective was to ‘deblur’ the seismic image sufficiently to enable improved stratigraphic interpretation. An additional challenge was the variable frequency-dependent amplitude loss over the centre of the structure due to overburden gas. This was addressed prior to SLI. Results were compared to a conventional SSI reflectivity inversion. In addition, the SLI results were tested for their suitability as input to acoustic impedance inversion.

Sparse Layer Inversion (SLI)

SLI is a sparse inversion parameterized to resolve layers thinner than tuning thickness. Conventional SSI is biased against thin layers since it uses the L1 norm of the total trace reflectivity to solve for a minimum number of non-zero reflection coefficients. SLI, in contrast, treats the seismogram as a superposition of layer responses (a weighted combination of odd plus even dipoles). Applying the sparseness criterion to layer responses rather than individual interface responses produces a sparse reflectivity inversion that does not discriminate against thin layers. Further, by using information from spectral decomposition of the seismic trace, possible sub-tuning layer responses can be weighted to drive the inversion towards preferred earth models. This inversion is performed trace by trace, with no continuity constraints or other spatial conveyance of information. Thus, the lateral continuity of the results is an indication of the stability and robustness of the algorithm.

UK Central North Sea Example

In a discovery located in the UK Central North Sea, oil was found in the Mey Sandstone Member of the Paleocene Lista Formation.

The Mey reservoir sandstones derive from topographically constrained, deep water turbidite flows (Kilham et al., 2012), the sands of which may be vertically amalgamated or separate. Each gross sandstone unit is below seismic resolution. The current seismic data is from a recent PreSDM processing of the CGGV Multi-Client Cornerstone survey. The bandwidth of approximately 10-40 Hz is insufficient to confidently interpret the Mey sandstone interval, which is sandwiched between the overlying Mey siltstone and upper Lista siltstone/shale intervals, with variable thickness and properties and the upper section of the Lista mass transport complex (MTC). This entire interval forms approximately one to two loops on conventional reflectivity data (Figure 1).

The SLI process was applied to the PreSDM full offset stack in an attempt to deblur and detune the original reservoir image and thereby provide better interface definition and aid stratigraphic interpretation and understanding (Figure 1). Before performing the SLI, gas-associated amplitude dimming was addressed by first splitting the seismic into five frequency bands. For each band, a “balancing map” was derived from RMS response over a long time window. Frequency band dependent corrections were applied to each trace before recombining the seismic through trace addition. To increase signal to noise levels we then applied a “mild” fault preserving structural filter.

Figure 1 The above images show a vertical section comparing the original stack (left) with the SLI output (right). An absolute acoustic impedance log is shown at the well intersection and the approximate thickness of the Mey Sst reservoir package is indicated by the arrows (CGG Multi-Client Data).

To provide layer information finer than conventional resolution, a constrained least-squares spectral analysis (CLSSA) was used to spectrally decompose the conditioned seismic (Puryear et al, 2012) and applied as a constraint to sparse layer inversion.

A time slice at approximate reservoir level is shown in Figure 2, highlighting the improved spatial detail seen on the SLI result compared with the input stack.

Figure 2 The above images show time slices through the Mey turbidite structure for both the unmodified stack (left) with the sparse layer inversion (right) after the stack was conditioned. At left, an area of dim reflectivity is apparent in the Northwest quadrant of the map. Frequency-dependent amplitude balancing was devised before performing the SLI shown at right (CGG Multi-Client Data).

To compare outcomes, the SLI output was also inverted to acoustic impedance (AI). Figure 3 shows the relative AI products from the original SSI versus the relative AI using the sparse layer inversion result.

Figure 3 The vertical sections compare relative acoustic impedance using a conventional sparse spike inversion (top) with that obtained using the sparse layer inversion outcome (bottom). The inserted log is absolute acoustic impedance. The SLI achieved clearer, consistent imaging of the Mey sandstone package (low relative acoustic impedance zone - indicated by arrows) and overlying siltstones (CGG Multi-Client Data).

The application of SLI extended the seismic bandwidth from 2 octaves to more than 3 octaves. Figure 1 shows that the response of the Mey interval has been successfully detuned by SLI and provides consistent well ties. The responses of individual lithological units can now be largely separated and the Mey sandstone package itself can be more confidently interpreted across the structure. Impedance inversion of the output of the SLI bandwidth extension (Figure 3) confirms the improved vertical detail achieved in comparison with the original SSI as well as the lateral stability of the result.

Conclusions

SLI aims to simplify complex thin bed interference patterns by producing a broad-band sparse reflectivity estimation. SLI, in contrast to SSI, does this by explicitly modeling the superposition of layer responses rather than single interfaces and so offers a geologically better founded solution. The example shows that at least a doubling of bandwidth is achievable, without noise amplification, and that the solution is laterally stable. For this example, the interference pattern at reservoir level is largely resolved using SLI, allowing individual unit identification and an improved stratigraphic

understanding of the reservoir sand package itself. Initial impedance work shows improved vertical detail when using the SLI as input over that seen on an earlier SSI impedance solution.

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