PARIS 2017

We A2 09

Improved Q Estimation and Application in the Time Domain with Broadband Seismic Data from the North Sea

A.J. Hardwick* (TGS), D. Woods (University of Leeds), H. Masoomzadeh (TGS), R. Clark (University of Leeds)

Summary

Broadband seismic enables us to move closer towards recovering the true earth response. The increased bandwidth should improve temporal resolution and reveal thinner beds to allow direct determination of commercial hydrocarbons from the data more easily. A paradox has been the focus on recovering low rather than high frequencies in broadband acquisition and processing.

To address this, we utilise 2000 km of recently broadband reprocessed long offset 2D data in the North Sea to derive temporally and spatially variant models of the seismic quality factor (Q) that can be used to compensate for attenuation and improve bandwidth. Automated Q estimation was performed on raw full final stacks along with angle stacks to consider the variation with offset to generate a pseudo 3D volume. Q estimates are applied to prestack gathers via a 1D ray tracer for travel times incorporating an antistretch correction and stabilisation scheme to prevent the boosting of high frequency noise, ensuring offset dependency for amplitude compliance. The models demonstrate a high degree of structural consistency which can be tied to formation tops from wells. The regional models can also be used an improved starting point for Q tomography, reducing the number of iterations required for convergence.

Introduction

A propagating seismic wave in an attenuating medium experience both absorption and dispersion. These effects are frequency and ray path dependent resulting in the preferential loss of higher frequencies causing reduced temporal resolution and phase distortion with increasing travel-times (figure 1). The full potential of broadband seismic data cannot be fulfilled until the effect of the earth filter is reversed requiring accurate knowledge of the seismic quality factor (Q) both temporally and spatially (e.g. Hardwick *et al*., 2012). Full compensation for attenuation effects also requires a robust approach to signal-to-noise cancellation such that the high frequencies can be recovered above the noise floor. In the absence of in-situ measurements from vertical seismic profiles (VSPs) it is desirable to estimate the quality factor from marine seismic reflection data directly. This is expressed as effective Q (Q_{eff}) describing the inseparable combination of intrinsic and apparent attenuation.

Here we utlitise 2000 km of recently broadband reprocessed long offset 2D data in the North Sea to derive a temporally and spatially variant regional Q_{eff} model which is structurally consistent and correlates to formation tops in wells using a stable automated algorithm based on the spectral ratio method (Dasgupta & Clark, 1998). Typically, this model is applied prestack to final normal moveout (NMO) corrected common depth point (CDP) gathers after prestack time migration (PSTM) in an offset-dependent and stabilized manner through 1D ray tracing for travel-times. An anti-NMO stretch correction is incorporated that would otherwise feign a decrease in amplitude verses offset (AVO). This model can also be used as a starting point for Q tomography.

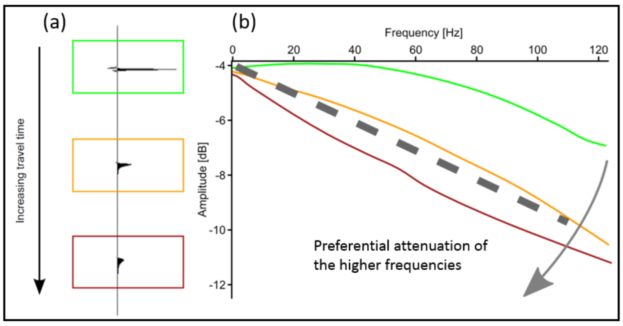

Figure 1 *The effect of seismic attenuation on a propagating wavelet resulting in (a) broadening of the pulse and reduction in amplitude with increasing time and (b) the associated amplitude spectra demonstrating the frequency-dependent nature.*

Rationale

Historical processing in the North Sea applies a singular Q_{eff} value for both amplitude and phase corrections ignoring local variations in lithology. Typically, the phase correction is applied before PSTM and the amplitude correction poststack. This simplistic approach is largely due to the difficulties of obtaining reliable estimates of Q_{eff} in the prestack domain before PSTM in the presence of poorer signal-to-noise, if the data is contaminated with multiples and the amplitude spectra contains free surface ghosts creating source and receiver side frequency notches. Application of the amplitude correction has also tended to intensify high frequency noise.

The optimum place for Q compensation to be applied is during prestack time or depth migration where it is necessary to have accurate Q_{eff} and velocity models in place. Ford (2014) found that using a structurally consistent Q_{eff} starting model estimated post-stack for Q tomography can have a significant effect on the final output and reduce the number of iterations required for converge to a global minimum using a workflow based on Xin *et al*., (2008) (figure 2). Although able to resolve local anomalies such as gas clouds, in the absence of a starting model, Q tomography failed to reliably estimate the longer wavelength background Q_{eff} field and had poor vertical resolution.

Method

We apply the commonly used approach of estimating Q_{eff} in the time domain whereby the ratio of two windows separated in time are computed sample-by-sample through a continuously time variant discrete Fourier Transform (DFT). The main parameters that fundamentally control the Q_{eff} estimates are the DFT window length and the maximum and minimum frequency cut as a fraction of the Nyquist frequency. Too short a window leads in unstable estimates varying rapidly both temporally and spatially whereas a window length too long would lack detail. The minimum and maximum frequency cutoff defines the seismic bandwidth over which the natural log ratio of the amplitude spectra is taken. Estimates are stabilised further by specifying a threshold (usually in unsigned dB) for spurious values in the slope fitting (figure 3).

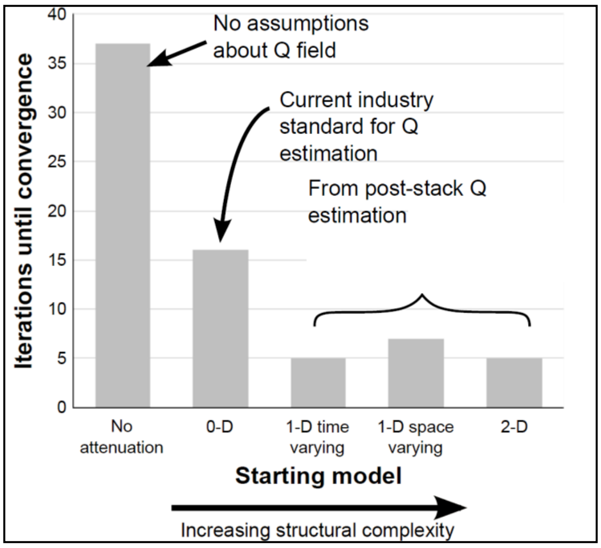

Figure 2 *(left) Starting models for Q tomography and iterations until convergence (Ford, 2014).*

Poststack Q_{eff} estimation was performed on raw full final stacks along with angle stacks to assess the variation of Q_{eff} with offset (QVO). Broadband data provides more reliable estimates due to a linear decay in frequencies through the removal of free surface ghosts and associated notches, tuning effects and overlapping primaries. An anisotropic (eta) correction was applied to the final NMO corrected gathers before stack removing the effect of NMO stretch out to a 44° angle of incidence. Applying the Q_{eff} estimates to prestack gathers for both phase and amplitude compensation a velocity field is used to account for the offset dependency of the correction with 1D ray bending and the effect of NMO stretching on the frequency content. The effect of this can be seen as a squeezing in the frequency domain (figure 4(a)). Q_{eff} correction can be applied after the anti stretch correction (figure 4(b)). The stabilization scheme of Wang (2006) is also incorporated to avoid the exponential boosting of high frequency noise (figure 4(c)).

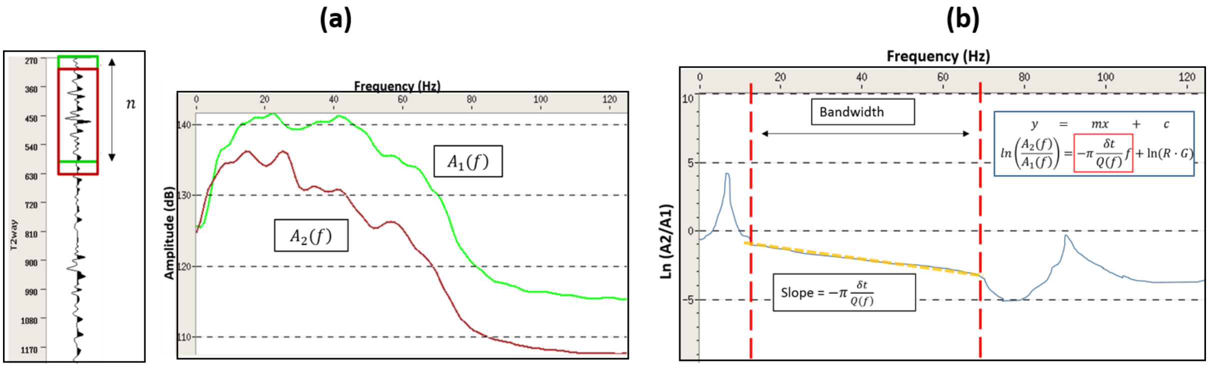

Figure 3 *Main parameters in the spectral ratio method include the window length n (a) and the bandwidth over which the natural log of the ratio is computed (b).*

Results

The 2D estimated Q_{eff} fields demonstrate a high degree of structural consistency. The 2D line intersections were tied by interpolation onto a 3D grid through minimum curvature gridding and appropriate smoothing. Regional 3D Q_{eff} cubes were produced for the raw full, near, mid and far angle stacks and timeslices through these cubes are shown in figure 5 for comparison. Unsurprisingly, QVO effects are more prevalent on the shallower timeslices due to the larger range of incident angles recorded. In all instances an interesting correlation with the Central Graben of the North Sea is shown that requires further attention as a potential seismic attribute.

(a) (b) (c)

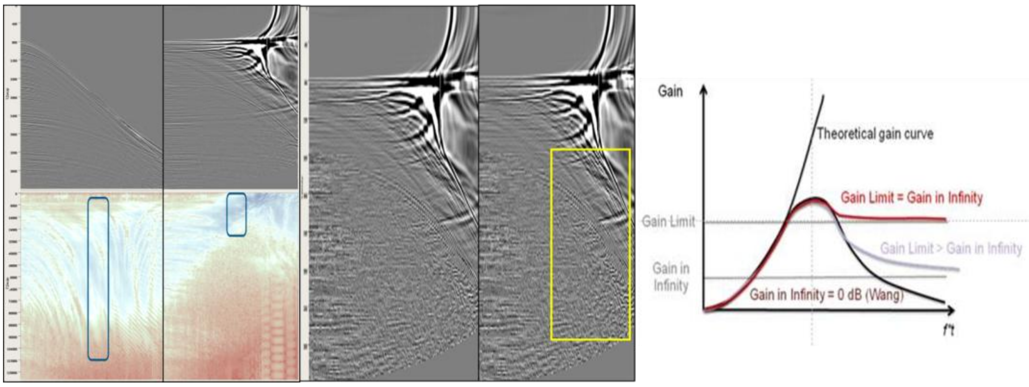

Figure 4 *(a) The effect of NMO stretch in the time and frequency domains; (b) CDP gathers with and without the anti-NMO stretch correction after prestack compensation for Q_{eff} via 1D travel-time computation and (c) the stabilization scheme of Wang (2006) incorporated in application.*

Figure 6(a) shows the temporal and lateral continuity of the raw full stack Q_{eff} field overlain on the broadband seismic data between two well locations some distance apart where individual formation tops can be tracked and correlated with consistent values. Figures 6(b) and (c) show the uplift in resolution by applying the estimated field in terms of an amplitude correction immediately pre-stack before stacking.

Conclusions

Reliable and structurally consistent regional Q_{eff} models have been obtained from legacy reprocessed broadband time data using the methods outlined in the North Sea. These pseudo 3D models can be used earlier on when processing new datasets and as an improved starting point for *Q* tomography. In association with the QVO analysis using angle stacks the models also provide the interpreter with an additional seismic attribute.

Acknowledgements

Jonathan Ford's and Daniel Wood's projects on seismic attenuation were conducted with TGS' Bedford Imaging centre as part fulfilment for an MSc in Exploration Geophysics at the University of Leeds under the supervision of Dr Roger Clark and the first author of this abstract. We also thank Connie VanSchuyver for reviewing ahead of submission.

References

Dasgupta, R., and Clark., R.A. [1998]. Estimation of Q from surface seismic reflection data. *Geophysics* **63**(6), 2120-2128.

Ford, J. [2014]. A Critical Analysis of a Q Tomography Workflow. Unpublished thesis, MSc Exploration Geophysics, University of Leeds.

Hardwick, A., Woodburn, N. and Whittaker, J. [2012]. Broadband Verses Conventional Marine Seismic: The Importance of Compensating for the Earth Filter. Workshop 11 – Broadband Seismic – Technical Value to Reservoir Characterization Workflows? *EAGE 74th Conference and Exhibition*.

Wang, Y. [2006]. Inverse Q-filter for seismic resolution enhancement. *Geophysics* **71**(3), V51-V60.

Woods, D. [2016]. A Critical Analysis of a Post-Stack Batch-Q-Estimation Algorithm. Unpublished thesis, MSc Exploration Geophysics, University of Leeds.

Xin, K., Hung, B., Birdus, S. and Sun, J. [2008]. 3D tomographic amplitude inversion for compensating amplitude attenuation in the overburden. *78th Annual International Meeting*, SEG, Expanded Abstracts, 27, 32-39.

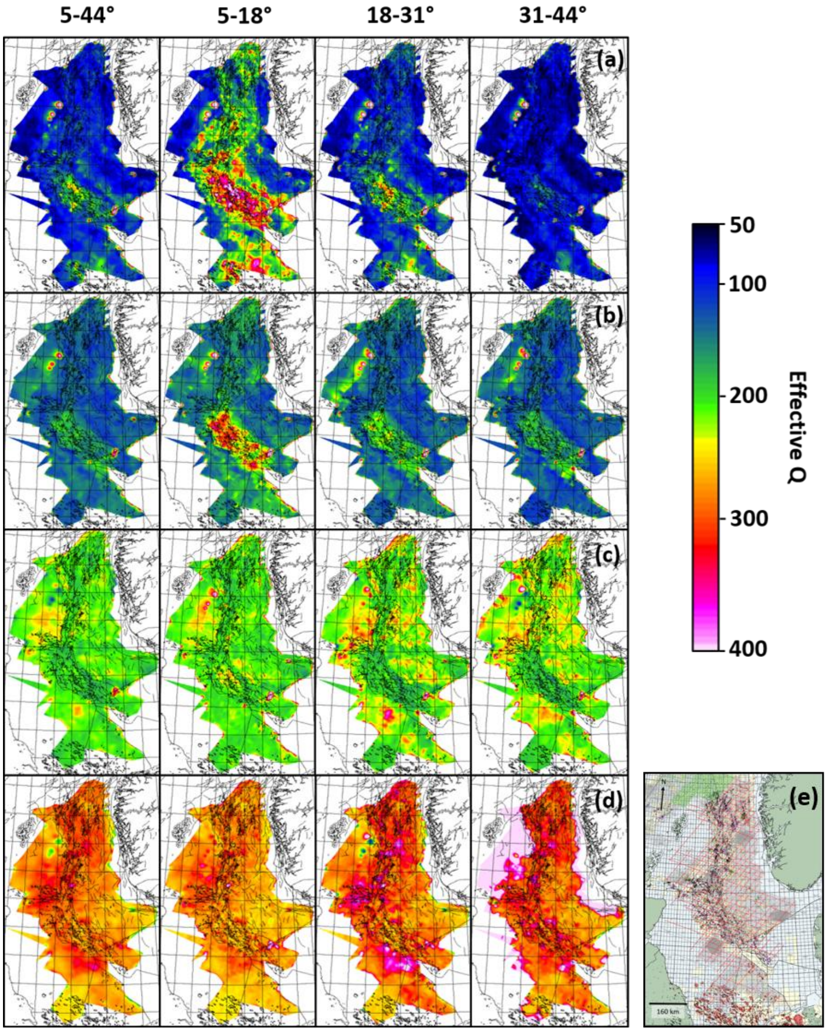

Figure 5 *Timeslices through the various Q_{eff} pseudo 3D model volumes at (a) 1 second (b) 2 seconds (c) 3 seconds and (d) 4 seconds TWT for the full raw and angle stacks with angle ranges indicated. Major structural elements and fields are overlain. Inset (e) shows the regional broadband reprocessed long offset 2D seismic lines used to generate the models with fields and wells illustrated.*

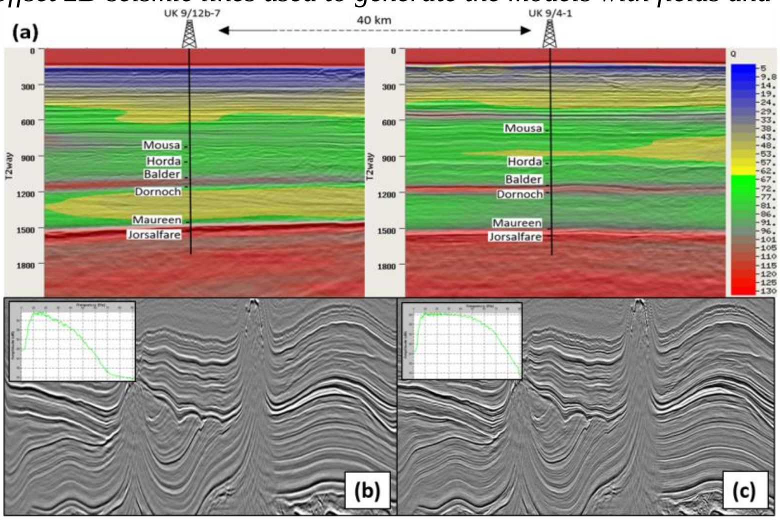

Figure 6 *(a) The temporal resolution and lateral continuity of the Q fields were analysed by observing them across formation tops at well locations. Q_{eff} estimates show consistent values across the section, in particular, the Balder formation which is 105 ± 6 at well UK 9/12b-7 and 109 ± 6 at well UK 9/4-1; (b) before and (c) after application of the derived Q_{eff} field with associated amplitude spectra for the window of data shown.*