WS07

Recent advances in Q model building and Q-compensating migration for imaging in the presence of complex gas clouds using P waves

N.I.L. Xie CGG
N.I.L. Wang CGG
N.I.L. Xiao CGG
N.I.L. Latter

Summary

The presence of absorption (Q) anomalies in the overburden, typically associated with gas accumulations, can obscure seismic imaging and reduce our ability to see and interpret events inside the resulting "shadow zone". In this paper we present our recent developments for addressing these challenges. We review progress made in the area of Q-compensating prestack depth migration (Q-PSDM) in order to deal with the co-existing multi-pathing and absorption effects for imaging through complex gas clouds using P-waves. In addition, to mitigate the problem associated with over-boosting of noise and migration artefacts introduced by Q-PSDM, more advanced imaging methods, such as least-squares Q-migration, have been developed to maximize the benefit of Q-PSDM. We then highlight a recently developed visco-acoustic full-waveform inversion (Q-FWI) model building technique for joint estimation of Q and velocity models. This has been applied to a production example from the Norwegian North Sea, where we see that the Q-FWI detects attenuating bodies of varying strength and scale throughout the survey and provides a clear uplift in the subsequent imaging process.

Introduction

Absorption effects in the Earth, often associated with gas accumulations and characterized by the Quality Factor (Q), can significantly attenuate the amplitudes and distort the phase of the seismic wavefield. If uncorrected this leads to obscured areas and poor imaging overall. A two-stage approach has been put forward for imaging beneath these features in the overburden: 1) Q-tomography to invert for a Q model (Xin et al., 2009), and 2) Q-compensating prestack depth migration (Q-PSDM) to compensate for the absorption effects during the migration process (Xie et al., 2009).

This approach has been an industry workhorse for imaging through and under gas clouds. However, when the distribution of the absorption bodies is more complex, we have the following challenges: Q-tomography can fail to provide a geologically plausible absorption model with the desired spatial resolution (Zhou et al. 2013) and, due to the limited near-offset data, Q-tomography inherently struggles in the shallow section, in regions that often contain strong Q bodies. Also, a complex overburden with sharp velocity contrasts and/or strong absorption anomalies will significantly distort the seismic wavefield, posing problems to ray-based Q-PSDMs that have difficulty in handling multi-pathing.

Q-compensating imaging

An ideal migration algorithm to deal with a complex overburden characterized by sharp velocity contrasts and strong absorption will be a Q-compensating reverse time migration (Q-RTM). By starting from the linear visco-acoustic wave equation in a TTI anisotropic medium, we have shown how to use wavefields from both a conjugate medium and a lossless medium to compute the desired backward propagated receiver wavefield (Xie et al. 2015). This method resolves the instability issue associated with the frequency-dependent attenuation in time-reversal propagation and deals with the multi-pathing and absorption effects for imaging through or under complex gas clouds using P-waves. Lin et al. (2016) clearly demonstrated the benefits of Q-RTM, in comparison with a conventional ray-based Q-PSDM, on a data set from offshore Brunei containing mega gas clouds.

Another challenge associated with Q-PSDM is that the frequency-dependent correction often over-boosts noise and migration artifacts, thus masking steeply dipping faults and weak reflectors. Least-squares migration offers an opportunity to mitigate these problems by including Q in the approach (Wu et al., 2017). Specifically, our preferred least-squares implementation is a single-iteration version (Khalil et al., 2016) where the inverse of the demigration-remigration operator (i.e., the so-called Hessian operator) is estimated using a 3D curvelet-domain matching filter (Wang et al., 2016). Thanks to the curvelet formulation naturally decomposing data into different frequency bands and dips, this least-squares Q-PSDM is able to correct for both absorption and illumination distortion, and attenuate random noise and migration swings, mitigating noise levels.

Visco-acoustic full-waveform inversion (Q-FWI)

Accurate Q and velocity models are critical for imaging beneath complex gas, with FWI offering the ability to obtain higher-resolution models than tomography. While inverting Q and velocity using FWI is highly desirable, a difficulty resides in the trade-off between the parameters as they have the same shape radiation pattern and, hence, their components have similar behaviour with scattering angle (see, for example, Malinowski et al., 2011). This means that angle-based considerations for discrimination of different model parameters, crucial in anisotropic and elastic FWI, are not applicable here. However, the absorption effects do undergo relative variation as frequency changes. Over a relatively broad range of frequencies, for strong anomalies inverted using wide aperture data, significant differences between the effects of velocity and Q become apparent, enabling Q-FWI to create meaningful updates (Malinowski et al., 2011). We have developed a Q-FWI technique driven by diving-waves for jointly estimating velocity and Q and applied it to a production data set from the Norwegian North Sea (Xiao et al., 2018). Figure 1 shows an example of the Q-FWI results up to 12 Hz over a region containing a set of previously unknown shallow Q bodies, highlighting them as potential drilling hazards. The spatial extent of the Q anomalies correlates well with the anomalies in the reflection data and clearly mitigates the image distortions following Q-PSDM (orange rectangles).

Acknowledgements

We thank CGG for permission to publish, CGG's Multi-Client & New Ventures division for permission to show the North Sea data set and the Horda-Tampen processing team for their support.

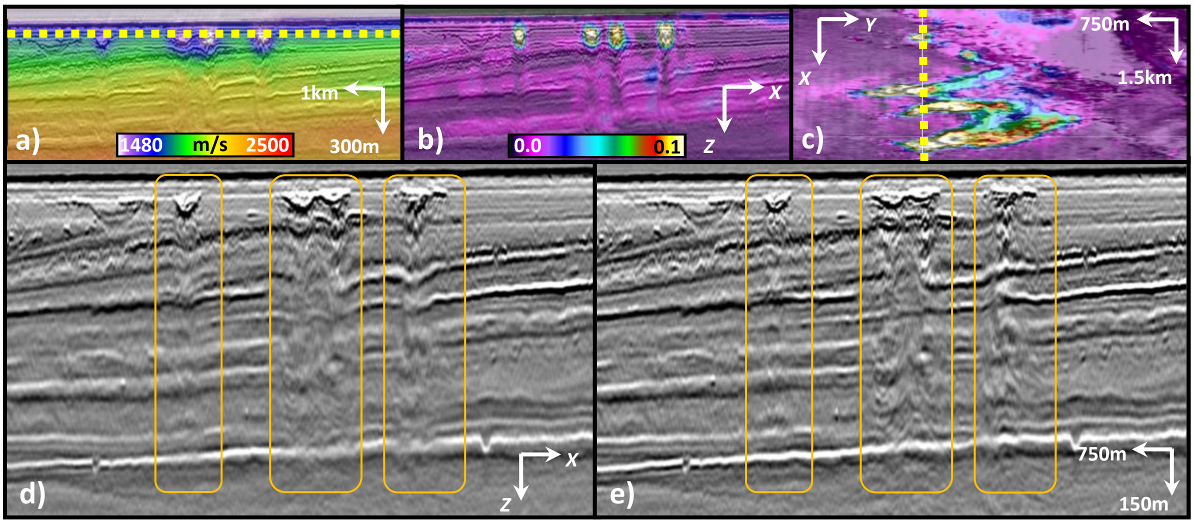

Figure 1 *Q-FWI results for shallow Q anomalies: (a) velocity inline section, (b) 1/Q inline section, and (c) 1/Q depth slice. The yellow dotted lines indicate the location of the inline and depth slices with respect to one another. Q-PSDM inline comparison of: (d) starting model, Q-migrated with a background Q value, and (e) Q-FWI output model, Q-migrated with the 12 Hz velocity and Q models. The orange rectangles highlight areas where the Q-FWI result has reduced the image distortion.*

References

Khalil, A., Hoeber, H., Roberts, G., and Perrone, F. [2016] An alternative to least-squares imaging using data-domain matching filters. *86th Annual International Meeting*, SEG, Expanded Abstracts, 4188–4192.

Lin, Y.N., Wu, X., Xie, Y., Zhou, J., Sulaiman, S., Turner, J., and Wei Z. [2016] Imaging through mega gas clouds in offshore Brunei. *78th EAGE Conference and Exhibition*, Extended Abstracts, Th LHR4 08.

Malinowski, M., Operto, S., and Ribodetti, A. [2011] High-resolution seismic attenuation imaging from wide-aperture onshore data by visco-acoustic frequency-domain full-waveform inversion. *Geophys. J. Int.*, **186**, 1179-1204.

Wang, P., Gomes, A., Zhang, Z., and Wang, M. [2016] Least-squares RTM: Reality and possibilities for subsalt imaging. *86th Annual International Meeting*, SEG, Expanded Abstracts, 4204-4209.

Wu, X., Wang, Y., Xie, Y., Zhou, J., Lin, D., and Casasanta, L. [2017] Least square Q-Kirchhoff migration: implementation and application. *79th EAGE Conference and Exhibition*, Extended Abstracts, Tu A1 08.

Xiao, B., Ratcliffe, A., Latter, T., Xie, Y., and Wang, M. [2018] Inverting near-surface absorption bodies with full-waveform inversion: a case study from the North Viking Graben in the Norwegian North Sea: submitted to *80th EAGE Conference and Exhibition*.

Xie, Y., Xin, K., Sun, J., Notfors, C., Biswal, A.K., and Balasubramaniam, M.K. [2009] 3D prestack depth migration with compensation for frequency dependent absorption and dispersion, *85th SEG Annual Meeting*, Expanded Abstracts, 2919-2923.

Xie, Y., Sun, J., Zhang, Y. and Zhou J. [2015] Compensating for visco-acoustic effects in TTI reverse time migration. *79th SEG Annual Meeting*, Expanded Abstracts, 3996-4001.

Xin, K., Hung, B., 2009. 3-D tomographic Q inversion for compensating frequency dependent attenuation and dispersion. *79th SEG Annual Meeting*, Expanded Abstracts, 4014-4017.
Zhou, J., Wu, X., Teng, K. H., Xie, Y., Lefeuvre, F., Anstey, I., and Sirgue, L. [2013] FWI-guided Q tomography and Q-PSDM for imaging in the presence of complex gas clouds, a case study from offshore Malaysia. *83rd SEG Annual Meeting*, Expanded Abstracts, 4765-4769.