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Improved Structural Imaging Using Joint Velocity and Q FWI on Ocean Bottom Seismic

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Summary

Gas absorption causes anelastic effects (described by the quality factor Q) and is a well-known source of amplitude loss and phase distortion in seismic data. Advances in full waveform inversion technology have recently offered a new possibility to compensate for phase distortion and amplitude loss by a joint update between velocity and the quality factor (Q). Several industrial applications on towed streamer data have recently been published. In this paper we present a new application on a North Sea dataset with gas present in the overburden. The dataset consists of wide azimuth ocean bottom P-wave seismic data, which is particularly favourable for application of FWI. We see that when combined with Q-Reverse Time Migration a good uplift in reservoir imaging is obtained.

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Introduction

Gas absorption causes anelastic effects (described by the quality factor Q) and is a well-known source of amplitude loss and phase distortion in seismic data. Moreover, successful imaging requires that both the Q and velocity fields be estimated as accurately as possible (Xie et al., 2015).

3D acoustic full waveform inversion (FWI) is a well-established method to generate high-resolution shallow velocity information and is routinely used as the first step in the creation of an imaging velocity field. Historically, variations from the background Q have been modelled using a priori well and velocity information or with inverse-Q filtering techniques. Whilst simple to implement, these methods are open to error and require a degree of manual intervention. More recently the development of a volumetric update for Q through the use of high-resolution tomography has proved to be very effective and several examples illustrating its successful implementation have been published, for example Gamar-Sadat et al., (2016). However, this method may not be suited to correcting shallow absorption anomalies, that is, where only near offset data is present.

Full waveform inversion technology has been expanded to compensate for phase distortion and amplitude loss by joint updates for velocity and the quality factor (Q) (Xie et al., 2018). In the industrial context several examples showing the effective application of Q-FWI have been published for towed streamer data such as Xiao et al., (2018). In this paper we present the results of Q-FWI derived on dense, wide azimuth ocean bottom seismic for a North Sea dataset with gas present in the overburden and show that when combined with Q-Reverse Time Migration (RTM) (Xie et al., 2015), a significant uplift in reservoir imaging is obtained.

Field and acquisition details

The input seismic comes from ocean bottom data recorded at Eldfisk which is situated in the southern part of the Norwegian North Sea. Water depth is reasonably shallow at approximately 70 metres and the reservoir is made up of naturally fractured Cretaceous chalk. Like similar fields in the area, the presence of gas in the overburden means that the reservoir is difficult to image creating seismically obscured areas (SOA).

Numerous seismic surveys have been conducted over Eldfisk to support development and reservoir monitoring; in more recent years acquisition has switched from streamer to ocean bottom with one of the intentions being improved imaging beneath the gas charged areas. For the Q-FWI modelling, raw hydrophone data were taken from the latest ocean bottom node survey, acquired in 2017. Source lines were acquired with a separation of 50m and shots were fired every 25m. Receiver lines were spaced 300m apart with 50m between each receiver, as illustrated in Figure 1.

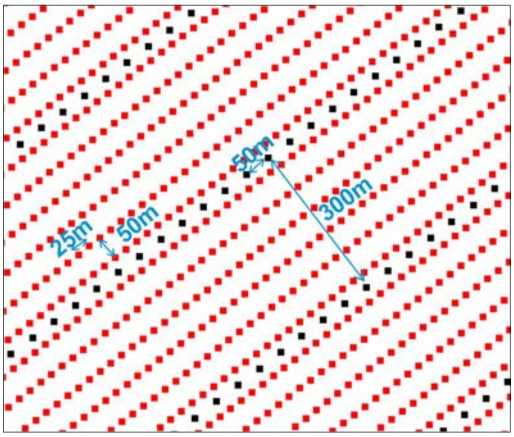

Figure 1 *Summary of the 2017 ocean bottom node survey acquisition configuration. The receiver lines are shown in black and the shot locations in red.*

Geophysical challenges

The main objective of the project was to reduce the extent and improve quality of imaging through the seismically obscured areas (SOA) using P-wave data. The velocity model building strategy was based on previous experience gained on data from similar geological settings in the North Sea such as the nearby Ekofisk and Tommeliten fields (Ratcliffe et al., 2014). In these cases (where ocean bottom data provides full azimuth and long offsets), diving wave driven full waveform inversion was used to update the shallow velocity model and was then followed by TTI multi-layer tomography to correct the deeper data. However, in order to avoid introducing any systematic velocity errors owing to shallow anelastic effects, a joint velocity-Q FWI update for the shallower data was proposed in favour of velocity FWI alone.

Method

A detailed legacy TTI imaging velocity model (derived from vintage ocean bottom cross-spread data) with joint Vp/Vs inversion and PP-PS joint tomography was used as the starting model. Additionally, information from 6 wells was used to support and verify the velocity model building process.

The raw hydrophone data was pre-conditioned by applying despiking, debubble filtering, low pass filter and inner/outer mutes. For the source wavelet, the modelled far-field signature was debubbled and compared with an equivalent wavelet extracted from the seismic data. Synthetic modelling trials were run for both and the extracted wavelet was selected for use in production as it produced a result which most closely resembled the field data. The initial Q-field was generated using well information and by identifying anomalously low velocities from the vintage imaging model.

Joint Q-FWI started at 3.5Hz on diving-wave offset limited data and progressed over several iterations to 10Hz with the mute opened to include all offsets and some reflections. Kirchhoff pre-stack depth migration (PSDM) and Q-RTM stacks (Xie et al., 2015) were used to monitor the data quality through the iterations. Cycle skipping QCs were carefully checked at all stages to ensure that the modelled field records matched the real data. Finally, any error in the deeper velocity information was updated using TTI multi-layer tomography.

Results

Analysis of the Q-FWI iterations showed improvements in the delineation of the velocity and inverse Q models which was supported by increased resolution and structural continuity on the imaged seismic data. Figure 2 displays a depth slice through a gas anomaly for the final Q-FWI output velocity and inverse Q models, with and without Q-RTM stack seismic overlaid. Both the velocity and inverse Q models correlate well with the geology.

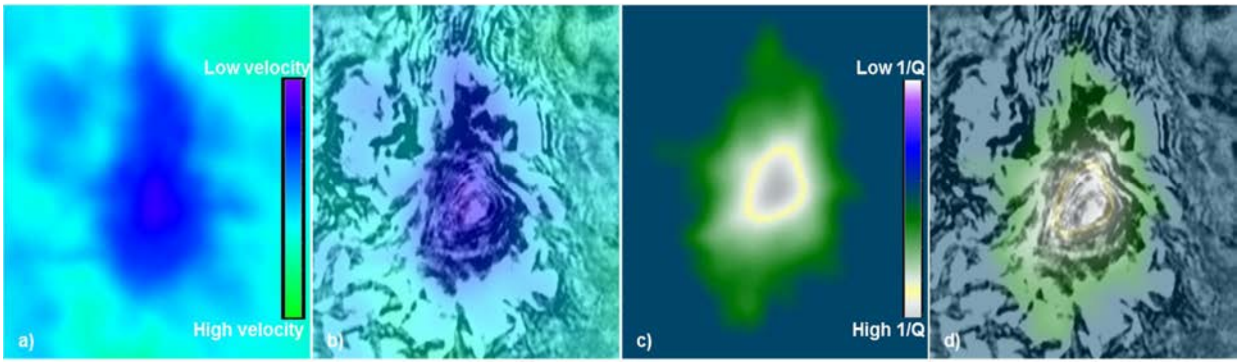

Figure 2 *Shallow depth slice showing Q-FWI results a) output velocity model b) overlaid with Q-RTM stack seismic and c) inverse Q model d) overlaid with Q-RTM stack seismic*

Figure 3 shows the results of Q-RTM generated using the vintage imaging velocity and a background inverse Q field (Figures 3a and 3b) to the final Q-FWI velocity and inverse Q result (Figures 3c and 3d). Note how the increased accuracy of the velocity through the shallow gas anomalies leads to considerable improvement in the imaging and continuity of the lower reservoir structure in part of the SOA.

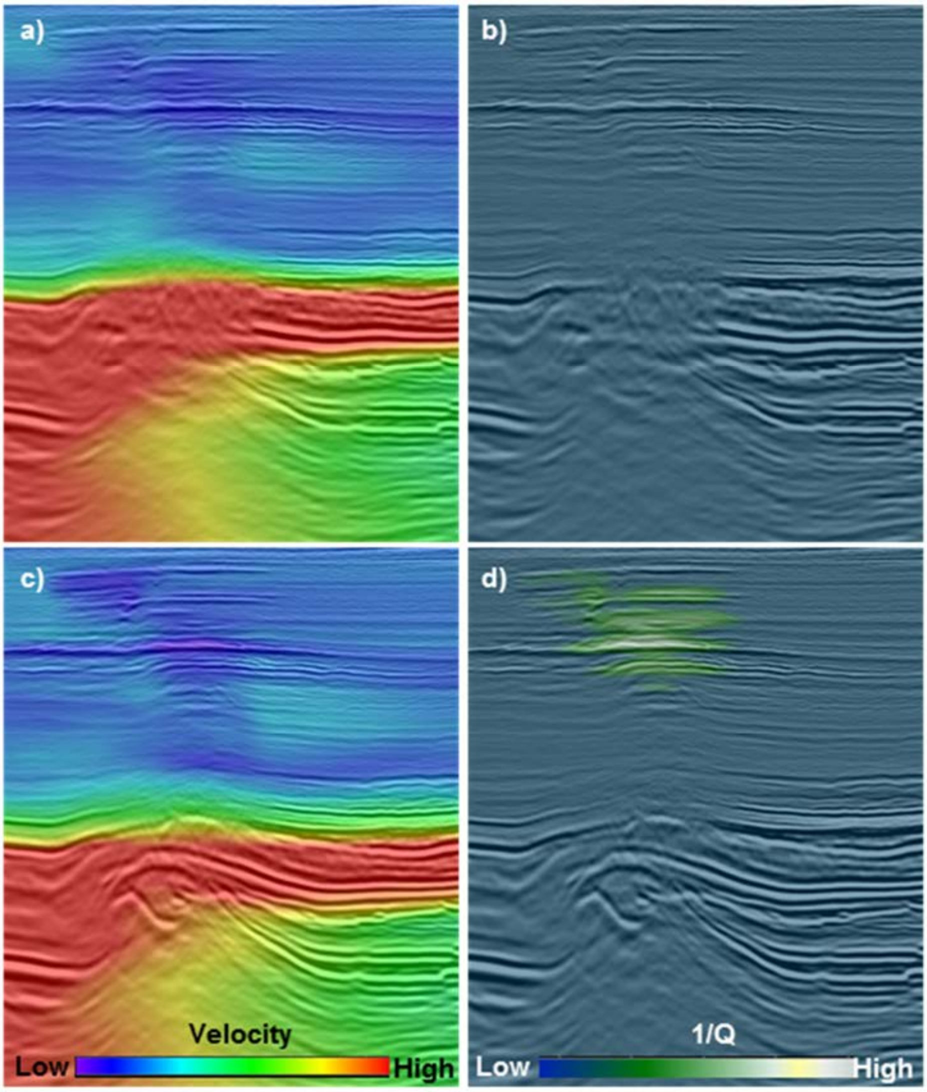

Figure 3 *Q-RTM stack generated with vintage velocity model (a and b) with a) vintage velocity and b) background 1/Q overlay. Q-RTM stack generated with final Q-FWI velocity model(c and d) with a) Q-FWI velocity and b) 1/Q overlay.*

Initial horizon auto-tracking (Figure 4) shows a significant improvement in trackable reservoir reflectors through parts of the SOA which is expected to result in an improved structural description of the field. Interpretation of the final Q-RTM results is still on-going, however, it is clear that these improvements will contribute to a better understanding of the field.

Future developments

As discussed by Xie et al. (2018) advances in least-squares Q-PSDM technology now mean that it is possible to image for higher frequencies without over-boosting noise or introducing migration artefacts. A future test for this data will be to see if least-squares Q-PSDM can unlock further improvements in structural continuity as demonstrated by Latter et al., (2018).

Conclusions

We have demonstrated on the Eldfisk ocean bottom node dataset that Q-FWI was successfully used to invert for both high resolution velocity and absorption anomalies. The increased delineation of the inverse Q and velocity fields, particularly in the gas structure has, in turn, led to a considerable improvement in the imaging of the reservoir and to a significant reduction in the size of the seismically obscured area.

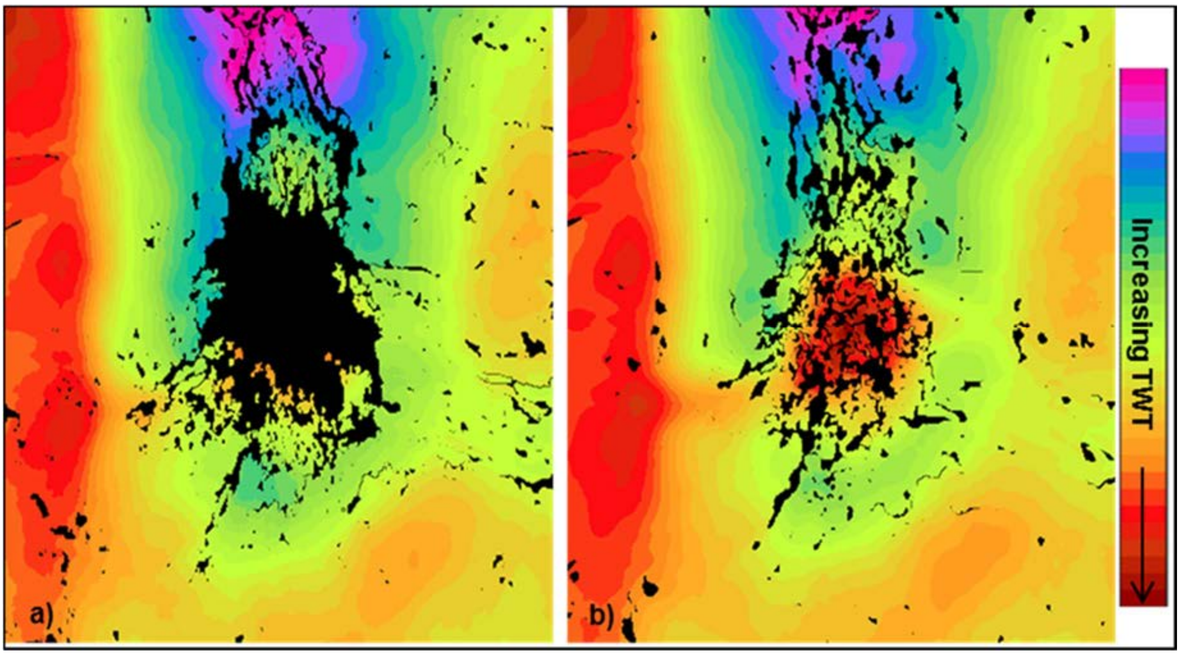

Figure 4 *Comparison of horizon auto-tracking around the top of the SOA a) picked on data imaged with the vintage velocity and b) picked on the Q-RTM stack output using the final Q-FWI velocity.*

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