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Application of Advanced Velocity Model Building and Migration Technology On Offshore North Africa Marine Dataset

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Summary

In recent years there has been tremendous progress made on the seismic migration and velocity model-updating technology to achieve better resolution and higher positioning accuracy, thus providing more valuable information to reduce exploration risk. In a dataset from offshore North Africa, the velocity model building is challenging due to a highly faulted geological setting and the presence of gas hydrates in the shallow overburden. Furthermore the image resolution beneath these diffracting and absorptive bodies is poor if we do not compensate for the resulting attenuation. This case study illustrates how a combination of sophisticated velocity update technologies, such as full waveform inversion and the latest tomography developments, together with Q-prestack depth migration, can achieve high quality seismic imaging.

Introduction

Reliable interpretation requires accurate imaging, itself dependent on the accuracy of the velocity model used in the migration. In the offshore North Africa dataset presented here, the velocity model building is challenging due to a highly-faulted complex structural setting and the presence of gas hydrates in the shallow overburden obscuring the target area. The resolution of the final image is poor if we do not compensate for the absorption in the gas hydrates areas and for the signal distortion caused by the fault networks.

With such a geological context, we opted for a depth processing workflow which included full waveform inversion (FWI) combined with high-definition (HD) tomography, volumetric Q-tomography, fault- and dip-constrained HD tomography. Our combination of these techniques leads to a detailed and trustworthy velocity model. We demonstrate how high-definition imaging can be achieved through the use of sophisticated technologies within the pre-stack depth migration (PSDM) sequence.

Dataset details

This case study consists of the processing of two 3D seismic surveys located offshore North Africa, acquired 5 years apart, totaling 7000 km^2 of conventional (i.e. non-broadband) seismic data, with water depths varying from 400 m to 3000 m. The area includes several geological complexities such as a rugose water bottom, a westwards-diving shelf edge, large areas of strongly-attenuating gas hydrates causing amplitude dimming in the target zone, the presence of carbonates and a high-velocity fan complex. The high-velocity channels are located 500 m to 1500 m below the water bottom. An area equivalent to about 30 % of the full merged survey is traversed by faults, adding even more complexity to the data processing.

Processing workflow

The main processing objectives were to improve the data quality in regards to a vintage processing for the older survey and to resolve spatial amplitude and velocity variations in the complex shallow structures considering the gas hydrates, trapped gas, complex seabed and shallow ‘hard’ amplitude for the merged survey. The two surveys were merged before time and depth migration.

The first objective of the processing was to enhance the seismic resolution by extending the seismic bandwidth. De-ghosting of the conventional dataset was undertaken using ghost wavefield elimination in the tau-p domain (Wang et al., 2013). The second objective was to improve both velocity model and imaging. We deployed enhanced velocity model building and imaging sequences which consisted of three key technologies combined: anisotropy FWI and HD tomography, Q-tomography and Q-PSDM, and finally dip and fault constrained HD tomography.

FWI and HD tomography
Gas hydrates are characterized by low velocities and high absorption, causing difficulties for imaging the events underneath. It is crucial to have an accurate, high-resolution velocity in these areas to get a high-quality image underneath. The first step of the velocity model building, using HD tomography, slowed down the velocities in the gas-hydrates to give a good input model for FWI (Ratcliffe et al., 2013). The shot gathers used for FWI were pre-conditioned with some new denoising tools including f-p domain processing (Yu et al., 2015).
In order to stabilize the FWI, we used two steps: a first update was performed using frequencies up to 5 Hz and only far offset refractions (over 3000 m). A second update used the whole offset range (both reflections and refractions) and aimed at increasing the resolution of the velocity field with frequencies up to 8 Hz. We obtained a reliable and high-resolution model (Figure 1, left), accurate enough to be input to the next step in the sequence.

Q-tomography

Solving absorption created by shallow gas-hydrates was one of the major imaging challenges in processing this dataset. Absorption can create strong amplitude loss, serious bandwidth degradation and influences the amplitude versus offset (AVO) behavior. As a result of the attenuation, the signal spectrum is shifted towards low frequencies. The frequency peak of a seismic wavelet is defined as the frequency at which the amplitude spectrum reaches its maximum. The Q-tomography approach we used consists of calculating a dense effective 4D Q volume (time, inline, crossline, offset), using the shift of the frequency peak from high to low values (Gamar-Sadat et al., 2015). Associated to RMO picks, effective Q picks are then converted into kinematic invariants that are inverted to obtain an interval Q model by tomography. The benefit of this workflow is that any interval Q anomalies are detected automatically. A low Q value is observed in the gas hydrates area in the shallow part of the section as shown in Figure 1, which correlates well with the observed low velocity.

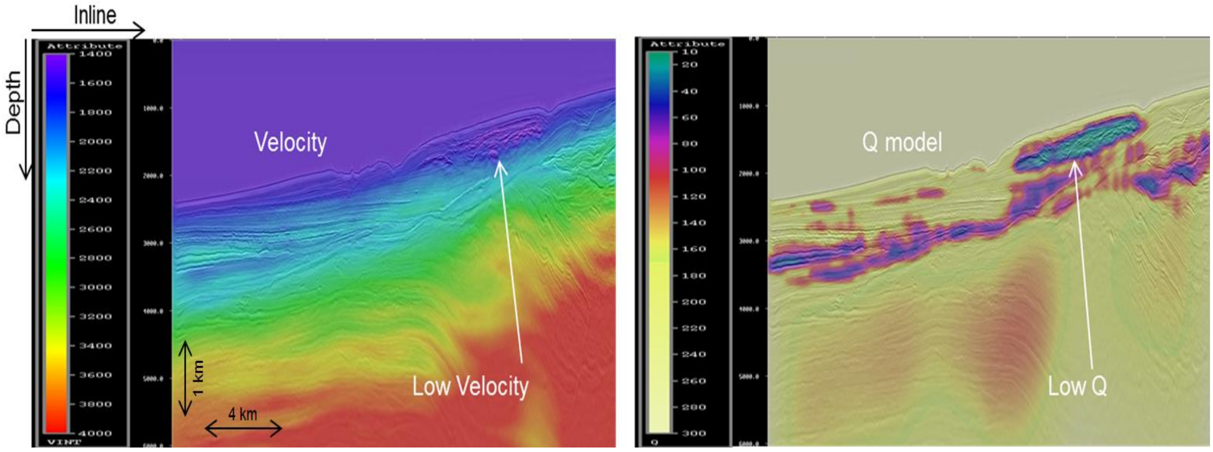

Figure 1 *Velocity and interval Q models: low Q values in the shallow (right) correlate well with the low velocity (left) corresponding to the gas hydrates area.*

The resulting volumetric 3D interval Q model (Figure 1, right) is then used in a Q-Kirchhoff depth migration (Q-PSDM) to compensate for dispersion and amplitude attenuation caused by the absorption along the actual wave-path. Figure 2 shows the results of using the volumetric Q-tomography model in the imaging process. On the stack section (Figure 2, right), the resolution is improved and many events become more visible, thus increasing our ability to interpret structures beneath the gas hydrate bodies and perform further velocity model update at deeper section.

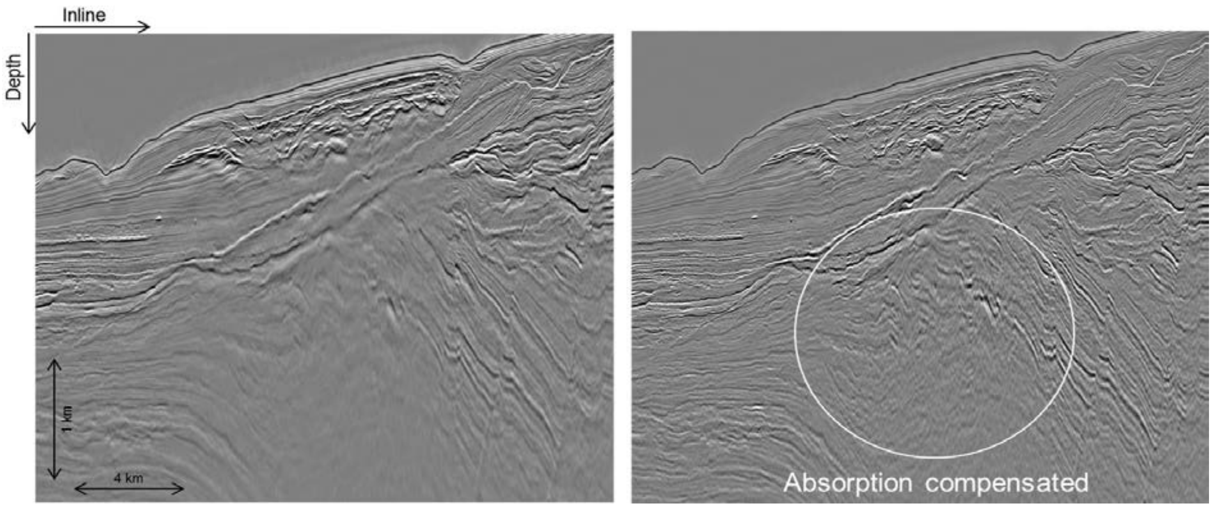

Figure 2 *Comparison of PSDM (left) and Q-tomography/Q-PSDM (right) results for the gas hydrates area: the white ellipse highlights the improvement in the imaging of the Q-PSDM using the volumetric Q-model.*

Dip and fault constrained HD tomography
About 30 % of the survey is traversed by faults which induce strong spatial velocity contrasts, often improperly captured by standard tomographic inversions. This results in distortion of seismic rays travelling across the faults and therefore a lack of seismic resolution below them, commonly known as fault shadows. Using fault interpretation provided by the client, a mask was produced which prevented the tomography from regularizing the velocity across the fault planes. To further help resolve the fault shadow issue, in particular some pull-down effects, a dip constraint in the tomographic inversion was used. With regular tomography, the velocity is updated in order to minimise a misfit function based on residual move-out curvatures. In dip-constrained tomography (Guillaume et al., 2013), the misfit function also includes the difference between a reference dip model (the target model) and the observed one (containing distortions caused by the faults), as well as the variability of the dips observed on different partial stacks (near, mid and far). Each sub-stack contains different distortion information corresponding to different illumination of the anomalies. Thanks to the combination of both fault and dip constraints, the output velocity model of this complex HD tomography is more detailed and geologically consistent (Figure 3), leading to a more focused and continuous seismic image with significant improvements below the fault planes (Figure 4).

Depth imaging results

Using a reliable, geologically consistent, velocity model combining FWI, HD, Q, fault and dip constraints in tomography improved the imaging of the whole dataset with recovery of the signal under gas hydrates bodies (Figure 2) and improved focusing in the faulted area (Figure 4).

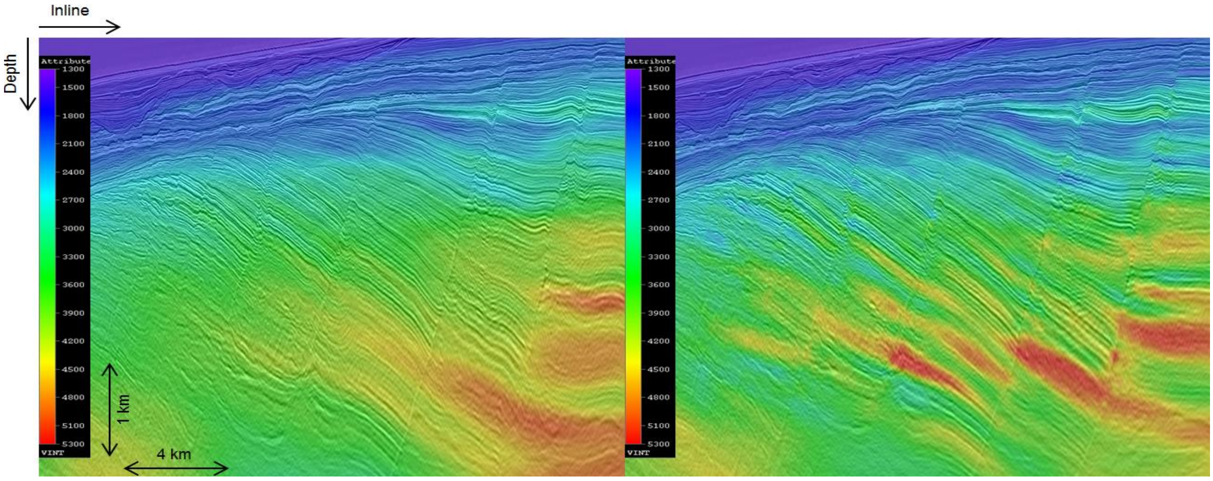

Figure 3 *Comparison of the velocity model before (left) and after (right) fault and dip constrained HD tomography.*

Conclusions

In this case study we have shown that, thanks to a customized processing workflow and velocity model building sequence, the geological and processing objectives were met. Q-tomography and Q-PSDM helped to resolve spatial amplitude variations, while the latest velocity update technology helped to adjust velocity variations in the presence of complex structures (gas pockets, faults, etc.). Combining several techniques, such as HD tomography, FWI, Q-tomography, joint dip and fault constrained HD tomography, to build the most reliable velocity field was necessary to obtain a high resolution and more focused migrated image in the presence of such complex geology.

Acknowledgments

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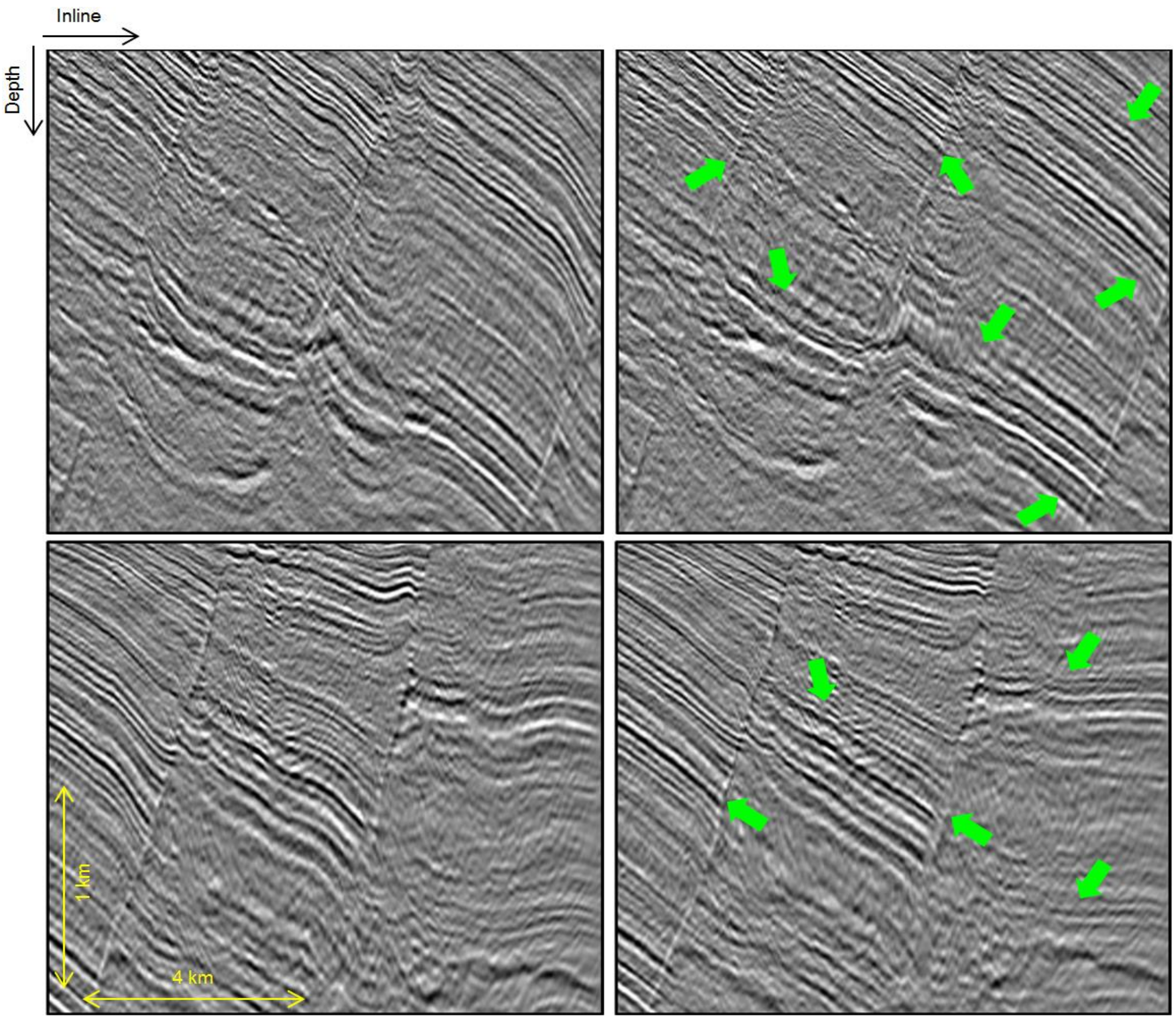

Figure 4 *Q-PSDM zoomed section using velocity model without (top and bottom left) and with (top and bottom right) fault and dip constrained HD tomography. Green arrows highlight the improvement in the structural shape and the continuity of the seismic image.*

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