WS1-01

Improving Subsalt Imaging by Image Conditioning and Enhancement with RTM Vector Image Partitions - A GoM Case Study

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SUMMARY

Subsalt imaging remains challenging despite a growing need for more accurate subsalt characterization. Long offsets, wide-azimuth (WAZ), and full-azimuth (FAZ) acquisition technologies have provided step-change improvements in illumination, multiple attenuation and signal-to-noise ratio. Recently developed more advanced anisotropic velocity model building techniques, have also greatly enhanced our ability to build accurate salt models and reduce velocity error. Reverse-time Migration (RTM) has become the preferred imaging algorithm due to its superior tolerance for complex salt geometry compared with traditional ray-based Kirchhoff migration. However, even with these developments, subsalt imaging still remains a significant challenge. Recently, Vector Image Partitions (VIPs) from RTM have proven valuable for enhancing the image of challenging subsalt structures. In this paper, we present a new method for optimizing the final migrated image through enhancement of the consistent signal and suppression of noise among VIPs. We demonstrate the effectiveness of this method with a case study from the Gulf of Mexico. The result shows great improvements in the subsalt image quality in terms of signal to noise ratio, reflector continuity, and wavelet consistency along reflectors.

Introduction

Many subsalt fields have been discovered and developed as the oil industry moves to deeper and more complex areas due to the depletion of shallow reservoirs. Risks associated with these deep subsalt fields keep increasing due to the complexity of geological structures, higher imaging uncertainties, and dramatically escalated drilling and development costs. Basins in the Gulf of Mexico (GoM), Brazil, and West Africa all share similar subsalt imaging challenges due to their complex salt canopies. Signal attenuation, scattering, contamination by multiples, and inadequate subsalt illumination are fundamental issues brought by complex salt geometry and sharp salt-sediment interfaces.

Efforts to address these problems have been broad, from acquisition to velocity model building to image enhancement and optimization. Long offsets, wide-azimuth (WAZ), and full-azimuth (FAZ) (Moldoveanu and Kapoor 2009) acquisition technologies have provided step-change improvements in illumination, multiple attenuation, and signal-to-noise ratios for subsalt imaging. Recent advances in anisotropic velocity model building workflows - and the use of full waveform inversion (FWI) - have also greatly enhanced our ability to build more accurate salt models and reduce velocity error. In addition, reverse-time migration (RTM) has become the preferred algorithm for subsalt imaging due to its superior tolerance for complex salt geometry compared with traditional ray-based Kirchhoff migration.

However, subsalt imaging still remains a significant challenge. Subsalt velocity model building remains imperfect because salt can introduce high noise levels associated with limited seismic illumination, which impairs our further efforts to update the model. Subsequently, strong coherent noise and low signal-to-noise ratios prevail in many subsalt areas, causing critical 3D coherent signals to be weak and buried in the noise. Vector image partitions (VIPs) from RTM give us the ability to isolate energy from different directions and, hence, enable us to differentiate signal from noise. VIPs have shown value for improving challenging subsalt structures through aiding localized seismic imaging (O'Briain *et al.* 2013), subsalt interpretation (Cogan and Boochoon 2013), and optimizing the final migrated image (Xu *et al.* 2011). In this paper, we present a new method for optimizing the final migrated image through enhancement of the consistent signal and suppression of noise among VIPs. We demonstrate the effectiveness of this method in case studies from the GoM. In addition to state-of-the-art acquisition, migration, and velocity model building technologies, results show that our new image conditioning and enhancement method is able to bring a step-change betterment of subsalt images.

Method

We refer to all techniques for optimizing the stacking process and forming the final image, from gathers or image partitions, as image conditioning and enhancement. Many such image conditioning and enhancement algorithms and methods have been shown to be highly effective at suppressing random noise by coherency or crosscorrelation-weighted stack (Liu *et al.* 2009; Zamboni *et al.* 2012), and improving signal stacking power by selective stacking (Xu *et al.* 2011) or by residual moveout correction of gathers (Manning *et al.* 2006). Combinations of different methods have also yielded impressive enhancement results (Manning *et al.* 2008). However, they still seem inadequate for fully addressing the unique subsalt image conditioning and enhancement challenge.

Coherent noise is one of the biggest challenges in subsalt imaging. Often, it originates from poor illumination introduced by complex salt-body structures. When coherent noise amplitude is stronger than signal, it introduces crossing events, leading to difficult and sometimes erroneous image enhancement and interpretation. Coherent noise may easily be erroneously treated as signal and enhanced by coherency-weighted stacking and residual moveout correction stacking; this is due to their inability to differentiate 3D coherent signal from strong random or coherent noise.

Velocity imperfection, which manifests as residual moveout on gathers, is another big challenge for subsalt image enhancement. Although residual moveout correction may effectively flatten gathers, it also tends to introduce cycle skipping and noise alignment. Our method intends to address these unique challenges.

We use polar or Cartesian VIPs (Figure 1) as our preferred input because they possess special advantages over other types of gathers, which makes them helpful for subsalt image enhancements. Random noise and weak coherent noise could easily be attacked with traditional crosscorrelation-based methods, provided a large enough (25 to 180) number of VIPs is used. VIPs also contain directional information that enables us to do selective stacking by incorporating geological interpretation. This is the first optional step of our new image-conditioning and enhancement process, one that allows us to suppress strong coherent noise from the very beginning. Then, from the initial selectively stacked or weight-stacked image, we derive a 3D pilot image volume with a structural skeleton and minimum noise, where all the important 3D geological features should be present. We use multiscale beamlet decomposition (originally developed for enabling fast beam migration described by Nichols and Tran (2008) to help extract weak coherent signal. Next, we calculate 3D weighting and 4D residual moveout corrections and apply them to all the VIPs where the 3D coherent signal alignment is ensured and the alignment of random or coherent noise is minimized. The final image is obtained through an iterative process of the above steps, where we seek to gradually bring improvements to the signal rather than a harsh one-step enhancement that could easily introduce artifacts.

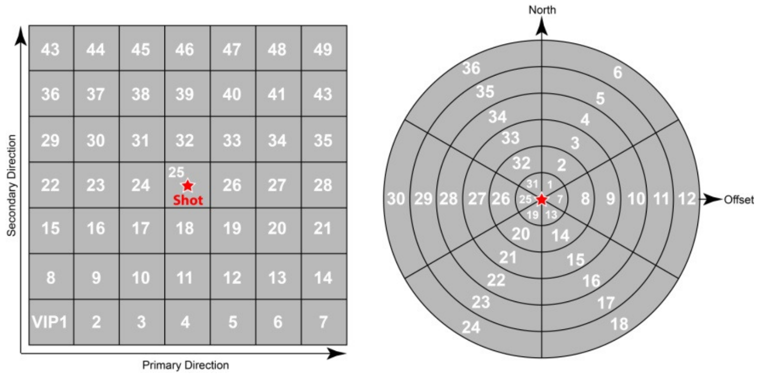

Figure 1 *Left) seven-by-seven Cartesian VIPs from RTM. Right) Polar VIPs with six azimuth and six offset bins.*

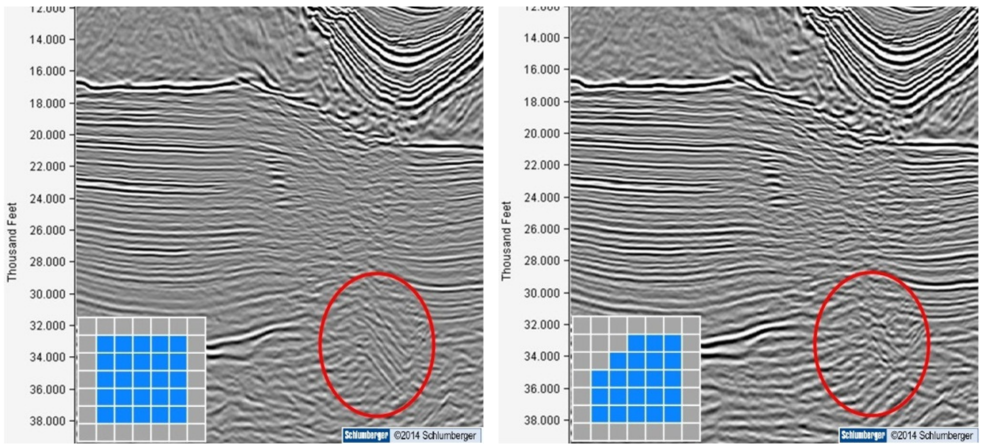

Figure 2 *Left) Weighted stack of middle 25 VIPs of all VIPs. Right) Weighted stack excluding three more problematic VIPs.*

Results on data from GoM

We use data from dual-coil acquisition from the central part of the GoM and a tilted transverse isotropy (TTI) model built using FWI (Vigh and Moldoveanu 2013). The selective stacking of VIPs and pilot construction part of this method plays a critical role in improving the final image. The collaboration between geological and geophysical expertise during this step, to enable image analysis and interpretation (Cogan and Boochoon 2013; O'Briain *et al.* 2013), has been proven valuable for understanding prospects under complex salt canopies, which, consequently, empowers us to suppress the strong coherent noise while making the true signal become obvious. Figure 2 shows that, by identifying the direction of the strong coherent noise, selective stacking of VIP volumes eliminates the contaminating coherent noise, while weighted stack alone fails to do so.

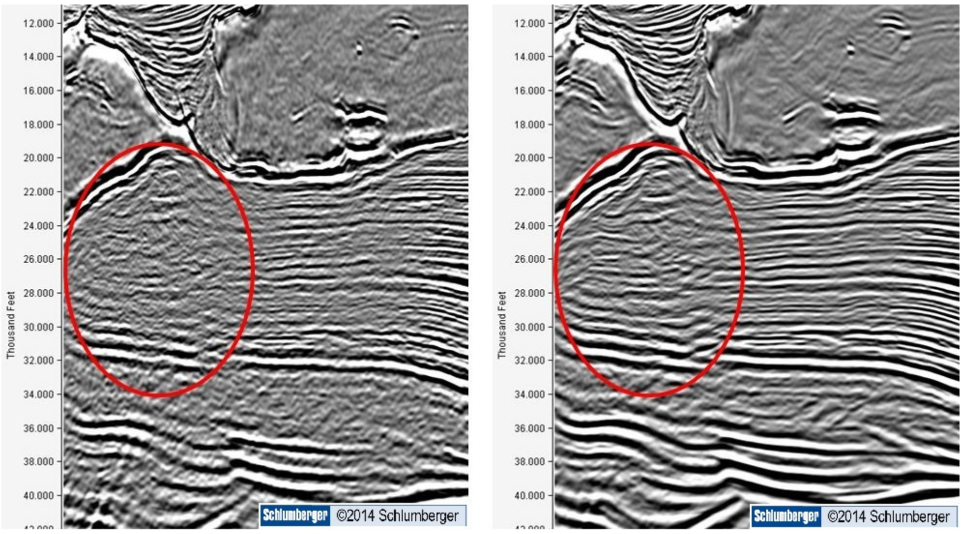

***Figure 3** Left) Raw stack image. Right) Image after image conditioning and enhancement.*

Driven by data itself, our method significantly improves image quality beneath complex salt geometry (Figure 3). Additionally, it is recognized that, in subsalt regions, low frequencies image better than high frequencies because of their reduced sensitivity to errors in the velocity model (Kapoor *et al.* 2005). In extremely challenging regions, where even large-scale structural signal is completely buried beneath high-frequency noise, our method is able to bring out the underlying, better-imaged, low-frequency component of the structure. Figure 4 also shows that, besides increased reflector signal continuity, our image conditioning and enhancement method can bring out coherent large-scale, low-frequency structures in extremely challenging subsalt regions.

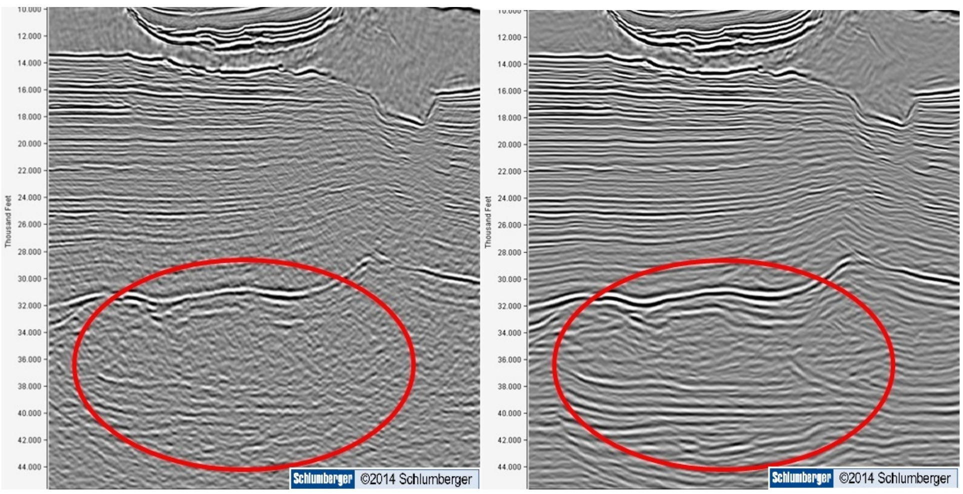

***Figure 4** Left) Raw stack image. Right) Stack after our image conditioning and enhancement.*

Conclusions

The proposed new image conditioning and enhancement method is data driven and is able to provide an array of enhanced image volumes, with parameters that control the enhancement from mild to extremely aggressive, depending on the need. With an enhanced broad structural picture and improved reflector continuity, our final image aids large-scale interpretation as well as providing assistance for other interpretation processes, e.g., horizon autotracking.

Acknowledgements

We acknowledge Schlumberger for providing seismic data for the data examples in this paper. We are grateful to Schlumberger for the permission to present this paper and to many colleagues who made this work possible.

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