Downloaded 10/25/19 to 192.159.106.200. Redistribution subject to SEG license or copyright; see Terms of Use at http://library.seg.org/

Purposeful seismic imaging for subsalt Wilcox stratigraphy

Mark Fan, R. Chadwick Holmes, and Rob Buehring, Chevron; Bing Bai, Qiaofeng Wu, Yao Zhao, and Serife Bitlis, CGG*

Summary

Ideal datasets for stratigraphic interpretation have high resolution, high level of continuity, high S/N, and high amplitude fidelity. In the deep water Gulf of Mexico (DW GOM), detailed geologic interpretation, like faults and channels, for subsalt Wilcox reservoirs is challenging due to complex salt overburden, poor illumination, and low resolution. However, it is becoming more feasible in recent years with advances in geophysics, i.e., new seismic data acquisition (e.g., WAZ, staggered WAZ with long offsets, and OBN) (Ourabah et al., 2015; Michell et al., 2017), velocity modeling technology (e.g., diving wave FWI, reflection FWI) (Peng et al., 2018), and more advanced imaging technology (e.g., LSRTM) (Schuster, 1993; Wang et al., 2016). In this paper, we present the customized workflow and results from a comprehensive reimaging project, with the purpose of preparing seismic data to reveal subsalt Wilcox stratigraphy.

Introduction

In DW GOM subsalt Wilcox reservoirs, faults and channels are among the key subsurface uncertainties. They are directly linked to reservoir connectivity and extent. Therefore, they strongly impact oil-in-place and field development planning. It is critical to have an accurate interpretation and estimation of the uncertainty ranges of these detailed geologic features. However, largely due to complex salt, poor illumination, and low resolution, it has been geophysically challenging to clearly image and interpret detailed faults and channels for subsalt Wilcox reservoirs.

High fidelity stratigraphic interpretation requires high frequency and resolution, high level of continuity, high S/N, and high amplitude fidelity. Recent geophysical advances make it possible to partially reach this goal. Long offset and low frequency acquisition surveys, like staggered WAZ, CWAZ, and OBN, provide the necessary diving wave information needed for high resolution supra-salt velocity updates using FWI. Reflection FWI (RFWI) can update the deeper sections based on reflecting waves in the data. RFWI has the advantage of updating velocities in low reflectivity zones by anchoring on any high-quality events below. The combination of FWI and RFWI is a powerful workflow to achieve a better overall velocity model for final migration. Additionally, time-lag FWI (TLFWI) (Zhang et al., 2018) can be applied to further fine tune the salt model when it is available. Least-squares reverse time migration (LSRTM) can compensate for weak subsalt illumination due to complex salt geometries. Therefore, the amplitudes of LSRTM seismic volumes are better balanced. However, it is important for the input velocity model to be close to the true model. These are the key geophysical technologies that were applied in this reimaging project.

Field Challenges

For this deep water GOM study area, the best existing seismic data is from a staggered WAZ survey acquired in 2014. It has both long offsets (up to 18 km) and low frequency content (down to 2.6 Hz). It was fully processed with the technologies available at the time, including 3D SRME, deghosting, TTI tomography, and salt interpretation and scenarios. The final image is a 35 Hz RTM.

By examining the existing dataset, we identified three main geophysical challenges in this area, which are the focus for the reimaging project:

1). A top-salt mini-basin, with large velocity uncertainty that results in poor subsalt image quality (Figure 1);

2). Base salt grooves, which generate uneven illumination (Figure 2) and associated subsalt artifacts (Figure 5a, Figure 6a);

3). Lack of clarity and continuity in observed channels (Figure 6a).

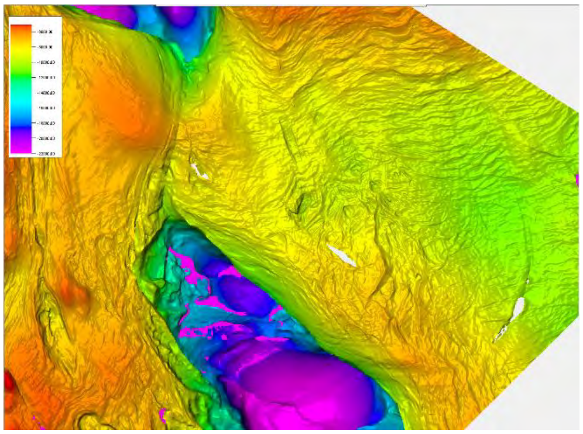

Figure 1: Top salt structure from seismic auto-propagation, which shows the details of the salt surface and complexity of the salt geometry in the mini-basin area.

Technology and Workflow

10.1190/segam2019-3216212.1

Downloaded 10/25/19 to 192.159.106.200. Redistribution subject to SEG license or copyright; see Terms of Use at http://library.seg.org/

Before achieving the characteristics of a better dataset for stratigraphic interpretation, these challenges are the first order issues that must be resolved. The following workflow was designed to specifically address them. First, diving wave FWI was applied to update the shallow sediment velocity. Tomography and RFWI were applied to complement the FWI velocity updates around the deep mini-basin and low reflectivity zone. Next, salt interpretation and scenario testing were conducted to fine-tune the detailed salt geometry. RFWI was used to guide the salt scenario tests. This type of detailed work captured many small improvements, which accumulated into a large overall image quality uplift. (Gomes et al., 2019). Third, RFWI and tomography were used to update the subsalt velocity. Finally, we applied TLFWI to fine tune the whole model. Well-tie tomography was conducted for both supra-salt and subsalt sediment velocity updates. After these first order challenges had been addressed, final migration was performed using 35 Hz LSRTM to obtain an adequate volume for stratigraphic interpretation. LSRTM was computationally expensive but critical to compensate the irregular illumination (Figure 2). Where the base salt was reasonably flat, rays reflected at a subsalt event were distributed relatively evenly. However, when a base salt groove was present, reflected rays were unevenly distributed, causing amplitude distortion. LSRTM helped resolve these subsalt groove artifacts and improve the S/N, amplitude fidelity, and subsalt event continuity. Therefore, the final volume can be used for attribute analysis of subsalt Wilcox faults and stratigraphy.

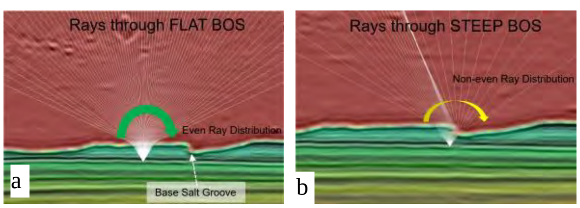

Figure 2. a: With flat base salt, reflection rays from subsalt events are evenly distributed, which indicates balanced illumination from sources and receivers. b: With a base salt groove (steep step salt boundary), reflection rays tend to be unevenly distributed, which produces irregular illumination.

Results

Results were carefully evaluated at each step. An arbitrary line shows the seismic image improvement from the new volume compared with the existing volume (Figure 3). More shallow sediment and top salt details were captured. Under the mini-basin, base salt was much better focused. Subsalt events were more continuous, with higher S/N and amplitude balance, which is ideal for stratigraphic analysis.

Supra-salt velocity updates and salt scenario tests led to a more detailed salt model. Figure 4b shows that the linear shaped base salt grooves were imaged much more clearly compared to the old base salt, with detailed extension, truncation, and continuity at various locations.

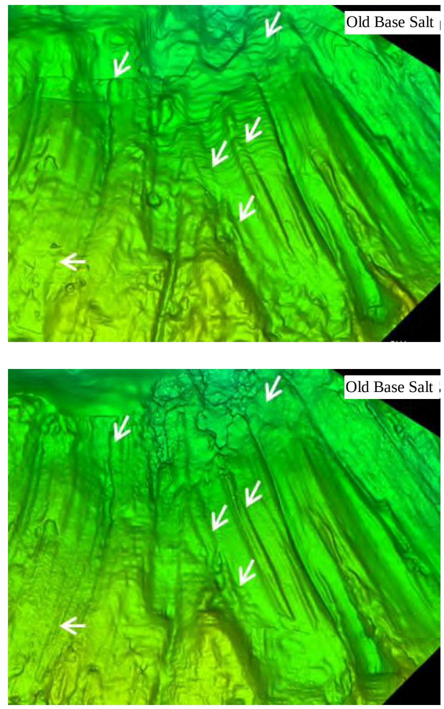

Figure 4. a: Base salt structure from old 35 Hz RTM; b: Base salt structure from new 35 Hz LSRTM.

LSRTM has largely attenuated the base salt groove artifacts associated with irregular illumination. Figure 5 is an amplitude extraction from the top of a subsalt Miocene surface. On the amplitude exaction map from the old volume (Figure 5a), the linear artifacts are the dominant features observed. Faults in the map (Figure 5a upper right corner) are not clear due to these artifacts. Figure 5b shows the amplitude exaction map from the final 35 Hz LSRTM. The linear subsalt groove artifacts are significantly reduced and the amplitude is more continuous. The three faults in the corner are imaged with greater confidence and resolution.

Downloaded 10/25/19 to 192.159.106.200. Redistribution subject to SEG license or copyright; see Terms of Use at http://library.seg.org/

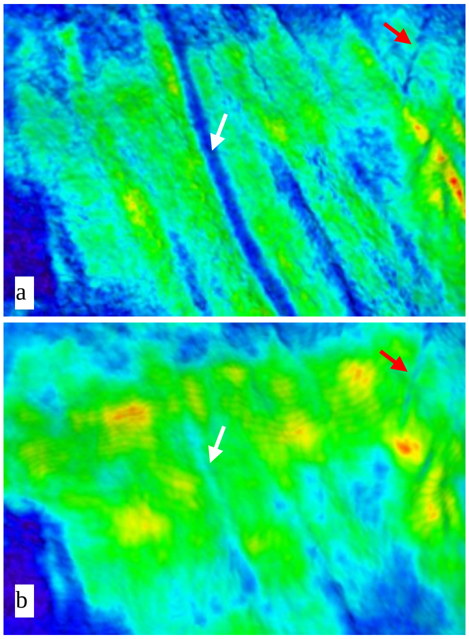

Figure 5. a: Amplitude extraction of a shallow subsalt event from the old 35 Hz RTM. Linear subsalt groove artifacts dominate the spatial variation in amplitude; b: Amplitude extraction of the same event from the new 35 Hz LSRTM. The artifacts are largely reduced, and faults in the upper right corner are clearly imaged with higher resolution.

At the Wilcox interval, linear subsalt groove artifacts dominate the amplitude map extracted from the existing volume (Figure 6a). There are some hints of possible channel features, but since the artifacts have similar amplitude levels as the channel features, it is very difficult to make a confident geological interpretation. In contrast, the details of the two channels are much clearer and easy to interpret in the new volume (Figure 6b) since the subsalt groove artifacts are largely attenuated.

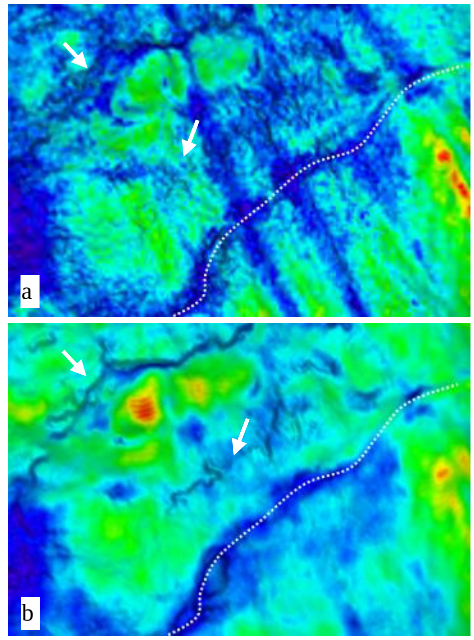

Figure 6. a: Amplitude extraction of a subsalt Wilcox event from the old 35 Hz RTM. The linear subsalt groove artifacts dominate the amplitude variation; b: Amplitude extraction of the same event from the new 35 Hz LSRTM. The artifacts are largely reduced, and channels are clearly imaged with more detailed structural variation.

Conclusion

By leveraging advanced technologies like FWI and RFWI, the velocity from the mudline down through the reservoir was largely improved, especially in the mini-basin. This improvement resulted in much more continuous subsalt events. LSRTM compensated the weak illumination due to base salt grooves. The subsalt groove artifacts were largely reduced, and a more complete picture of channel morphologies was revealed. Another benefit of applying LSRTM is that it resulted in higher S/N and amplitude fidelity than conventional RTM. However, some challenges remain: subsalt events under the mini-basin are not imaged as well as neighboring areas and residual subsalt groove artifacts persist. Additional new data, like OBN and 3D VSP, may be needed to further resolve these challenges.

Acknowledgments

The authors thank the management of Chevron and CGG for permission to publish this work. We also thank BP for their input and support during the reimaging project.

Downloaded 10/25/19 to 192.159.106.200. Redistribution subject to SEG license or copyright; see Terms of Use at http://library.seg.org/

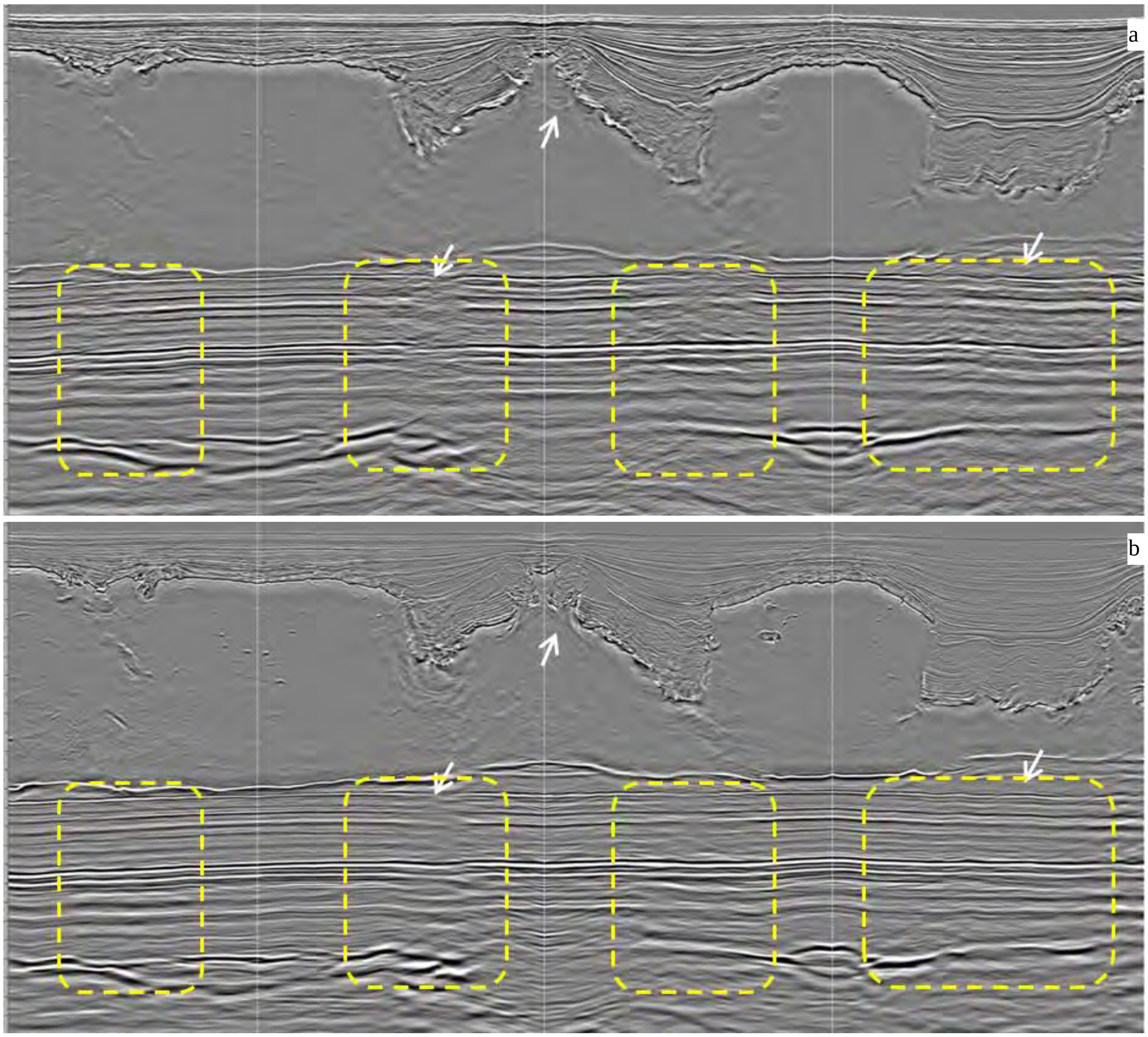

Figure 3: Arbitrary seismic line from previous (a) and current (b) volumes. Compared to the old volume, the new volume shows better imaging of details in the shallow sediments and top salt. Base salt underneath mini-basin areas are better focused. Subsalt events are more continuous, with higher S/N and better amplitude balance.

REFERENCES

Gomes, A., J. Peterson, S. Bitlis, C. Fan, and R. Buehring, 2019, Assisting salt model building with reflection full-waveform inversion: Interpretation, **7**, no. 2, SB43–SB52, doi: https://doi.org/10.1190/INT-2018-0155.1.

Michell, S., X. Shen, A. Brenders, J. Dellinger, I. Ahmed, and K. Fu, 2017, Automatic velocity model building with complex salt: Can computers finally do an interpreter's job?: 87th Annual International Meeting, SEG, Expanded Abstracts, 5250–5254, doi: https://doi.org/10.1190/segam2017-17778443.1.

Ourabah, A., J. Keggin, C. Brooks, D. Ellis, and J. Etgen, 2015, Seismic acquisition, what really matters?: 85th Annual International Meeting, SEG, Expanded Abstracts, 6–11, doi: https://doi.org/10.1190/segam2015-5844787.1.

Peng, C., M. Wang, N. Chazalnoel, and A. Gomes, 2018, Subsalt imaging improvement possibilities through a combination of FWI and reflection FWI: The Leading Edge, **37**, no. 1, 52–57, doi: https://doi.org/10.1190/tle37010052.1.

Schuster, G. T., 1993, Least-squares crosswell migration: 63rd Annual International Meeting, SEG, Expanded Abstracts, 110–113, doi: https://doi.org/10.1190/segam2012-1425.1.

Wang, P., A. Gomes, Z. Zhang, and M. Wang, 2016, Least-squares RTM: Reality and possibilities for subsalt imaging: 86th Annual International Meeting, SEG, Expanded Abstracts, 171–173, doi: https://doi.org/10.1190/segam2016-13867926.1.

Zhang, Z., J. Mei, F. Lin, R. Huang, and P. Wang, 2018, Correcting for salt misinterpretation with full-waveform inversion: 88th Annual International Meeting, SEG, Expanded Abstracts, 1143–1147, doi: https://doi.org/10.1190/segam2018-2997711.1.

Downloaded 10/25/19 to 192.159.106.200. Redistribution subject to SEG license or copyright; see Terms of Use at http://library.seg.org/