Enhanced pre-stack depth imaging of wide-azimuth data from the Gulf of Mexico: a case history

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Summary

We present a case study of enhanced imaging of wide-azimuth data from the Gulf of Mexico utilizing recent technologies; and we discuss the resulting improvements in image quality, especially in subsalt areas, relative to prior methodologies. The input seismic data set is taken from the large scale Freedom WAZ survey located in the Mississippi Canyon and Atwater Valley areas. In the course of developing the enhanced wide-azimuth processing flow, the following three key steps are found to have the most impact for improved subsalt imaging. 1) Data regularization to prepare the data for multiple attenuation as well as for the final run of anisotropic reverse time migration; 2) 3D true azimuth SRME to remove multiple energy, in particular, complex multiples beneath salt; 3) reverse time migration based delayed imaging time (DIT) scan to update the complex subsalt velocity model. The DIT scan further improves the accuracy of the subsalt velocity model after the conventional ray-based subsalt tomography. In this paper, we focus on the depth imaging aspects of the project, with particular emphasis on the application of the DIT scanning technique. We also demonstrate the uplift of acquiring a wide-azimuth data set relative to a standard narrow-azimuth (NAZ) data set.

Introduction

Early forward modeling experiments demonstrated that significant improvements in imaging and multiple attenuation were possible with wide-azimuth data (Regone, 2006; VerWest & Lin, 2007). Initial field data trials quickly followed using ocean-bottom nodes (Ross & Beaudoin, 2006), and streamer data was acquired with a range of acquisition scenarios (e.g. Corcoran et al., 2007; Howard & Moldoveanu, 2006; Threadgold et al., 2006). The results from these surveys confirmed the modeling results, but also raised interesting questions about how best to optimize the processing sequence for WAZ data (e.g. Michell et al., 2006). As more data has been acquired, the initial promise of better imaging and reduced multiple content has not consistently been fulfilled. Geophysicists have been working hard to understand the issues involved and to develop processing best practices that result in the maximum amount of uplift from wide-azimuth data (Fromyr et al., 2008).

In our enhanced WAZ processing flow, the following three key steps are found to have the most impact for improved subsalt imaging. 1) Data regularization to prepare the data for multiple attenuation and for the final run of anisotropic reverse time migration (RTM); 2) 3D true azimuth SRME to remove multiple energy (see Figure 1), in particular complex multiples beneath salt; 3) RTM-based delayed imaging time (DIT) scan is used to update the complex subsalt velocity model. DIT scan further improves the accuracy of the subsalt velocity model after the conventional ray-based subsalt tomography. In this paper, we focus on depth imaging and present more details regarding the application of the newly developed DIT scan.

For comparison, we have a NAZ data set available in the study area which allows us to study the improvement gained by acquiring WAZ data relative to standard NAZ data. We also compare the image quality resulting from different anisotropic migration algorithms (Kirchhoff vs. RTM) using the same velocity model and the same WAZ input data.

RTM based DIT scan

We have developed a new methodology of subsalt velocity updating using RTM-based DIT scan (Wang et al., 2009), which consists of the following primary components: 1) Generation of a subsalt RTM based DIT scan; 2) Picking of DIT values by comparing different RTM based DIT scan images; 3) Subsalt velocity update using the picked DIT values. In order to generate an RTM-based DIT scan, any existing RTM code is easily modified to apply non-zero-time imaging conditions along with the standard zero-time condition. The picking tool for the DIT scan is similar to those originally designed for regular WEM-scan picking (Wang et al., 2006); but instead of a velocity scaling factor, the picked values represent the time-shifts (such as -100 ms or +200 ms) where primary reflection energy is best focused. Both stacked sections and gathers are used for picking. To facilitate picking, gathers are also converted to pseudo-semblance. Figure 2 shows an example of DIT scan panels. In this example, for the negative time-shift case, the subsalt events are much better focused.

Composite RTM image based DIT scan picking

One benefit of DIT scan analysis is the ability to produce a better focused composite image. To produce the composite image, we convert each time-shifted DIT scan image to pseudo-depth domain by applying the following steps: 1) depth to time conversion; 2) compensation for the time-shift applied during the time-shift imaging condition; 3) time to depth conversion. The composite image is generated interactively during the picking process to evaluate the validity of the picks.

Figure 3C is a real data example of the composite image after the DIT scan picking. Compared with the regular RTM image (Figure 3B), the composite image (Figure 3C) is much better focused and subsalt events are more coherent. This indicates that the trend of the updated picks is correct. Figure 3A shows the DIT value picking interface.

The composite image can serve two purposes: 1) to QC the DIT scan picking; 2) to produce the best focused final image. The composite image is expected to be equal or better in quality as compared with the regular image corresponding to DIT equal to zero. Any degradation of the composite image in any portion indicates picking errors. The composite image (Figure 3C) based on DIT scan picking is better focused and more coherent compared to the regular anisotropic RTM image (Figure 3B). This allows further improvement of the final image that was limited by the inevitable inaccuracies in the velocity model.

Subsalt velocity update using RTM-based DIT scan

This new RTM-based DIT scan subsalt velocity update has been successfully applied to update the subsalt velocity model. Figures 4 shows the RTM image before and after the subsalt velocity update using the RTM-based DIT scan. In this example, 21 RTM-based DIT scan images are produced. The initial velocity model already has ray-based subsalt tomography, which is well-suited for most of the subsalt velocity model. Using the subsalt scan picking tool, delayed imaging times are picked by comparing scan panels (stacked images) as well as gather displays, similar to WEM scan picking (Wang, et al., 2008). After the DIT scan subsalt velocity update, RTM is rerun using the newly updated velocity model.

Image Improvements

While the pre-processing, regularization and multiple attenuation schemes are important, the single biggest uplift in wide-azimuth data appears in the imaging step through the additional illumination provided by increased azimuth coverage. Since they provide an efficient way to take advantage of wide-azimuth acquisition's relatively sparse shot distribution, shot-based wave equation techniques such as WEM and RTM are best suited to imaging wide-azimuth data. However, Kirchhoff and beam migrations are also used during the model building phase.

In Figure 5 we show a comparison of narrow azimuth versus wide azimuth results using Kirchhoff pre-stack depth migration. The model is the same and all algorithms incorporate VTI anisotropy. The wide-azimuth data has no multiple attenuation, while the legacy narrow azimuth data has been through 2D SRME and radon. The uplift from increased illumination, especially for deep subsalt reflectors, can be clearly seen.

The Kirchhoff and RTM comparison example (Figure 6) shows the improvement resulting from using a high-end migration algorithm in conjunction with wide-azimuth acquisition. Complex subsalt structures can be identified on the RTM data, as RTM combines the steep-dip capability of Kirchhoff and the multi-pathing capability of WEM. Additionally, RTM uses a more accurate two-way wave propagator and is able to handle other complex wave modes such as Prism waves; resulting in a better RTM image in the shadow zone below the steeply dipping base of salt (BOS), and subsalt sediment events have better termination at the salt boundary. The RTM algorithm implements a more accurate illumination compensation, which makes subsalt amplitudes more accurate and better balanced than the Kirchhoff image.

Conclusions

There are many new challenges associated with processing wide-azimuth data and many old challenges are cast in a new and more complex light. Compared to the NAZ image, the WAZ has an improved subsalt image in many of the complex areas, primarily due to the additional illumination provided by increased azimuth coverage. Comparing different anisotropic pre-stack depth migration algorithms (Kirchhoff vs. RTM) using the same model and input seismic data, we see that RTM combines the strengths of Kirchhoff (steep-dip) and of WEM (multi-pathing for subsalt image). RTM is clearly superior in the subsalt shadow zone, and the amplitudes are better balanced.

We have applied the new methodology of subsalt velocity update using RTM-based DIT scan. RTM-based DIT scan only requires one pass of RTM followed by multiple time-shifted imaging conditions. This RTM-consistent subsalt velocity update method allows us to further improve the subsalt velocity model subsequent to the application of ray-based subsalt tomography.

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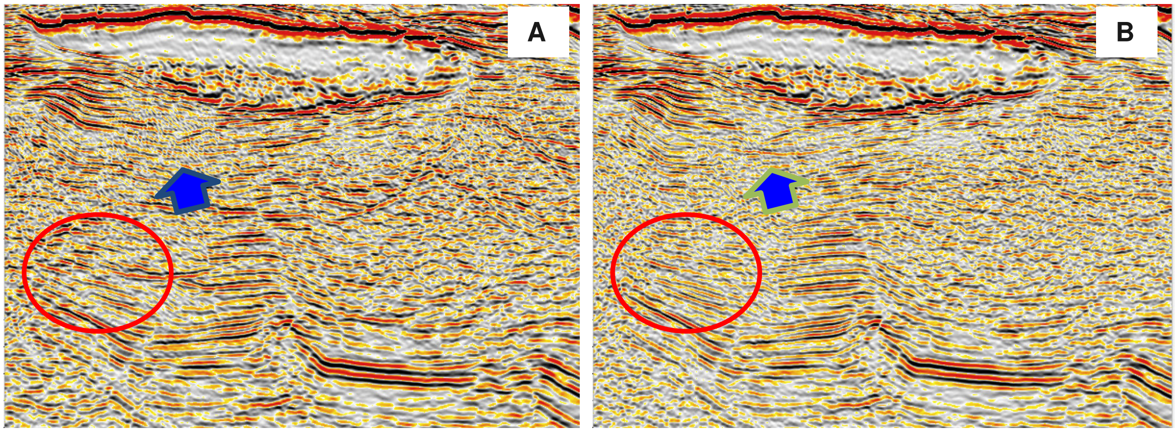

Figure 1: *A) Single sequence RTM image without SRME; B) Single sequence RTM image with 3D true azimuth SRME*

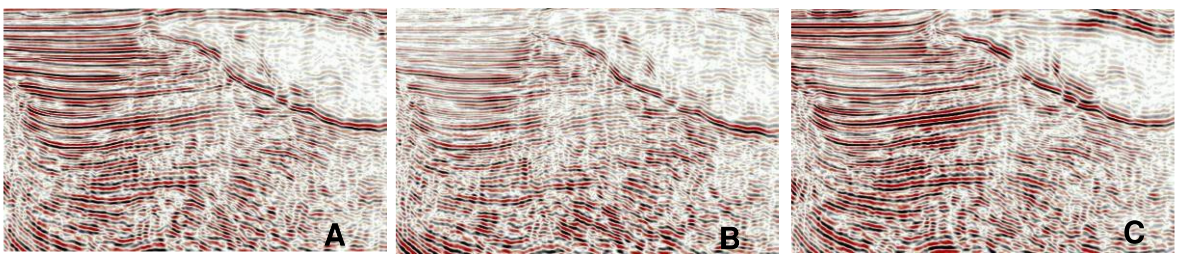

Figure 2*: An example of DIT scan panels with delayed imaging time: A) 0 ms; B) + 100 ms; C) - 100 ms*

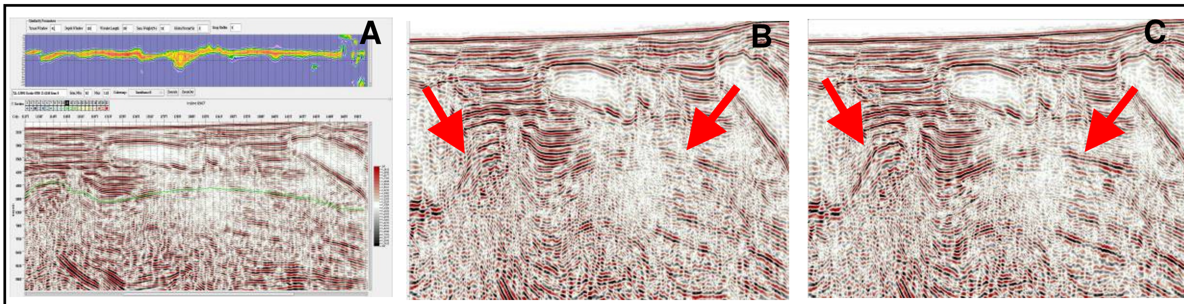

Figure 3: *A) DIT scan picking interface; B) Regular RTM image using initial velocity model; C) Composite RTM image using the same initial velocity model as Figure B, after DIT scan*

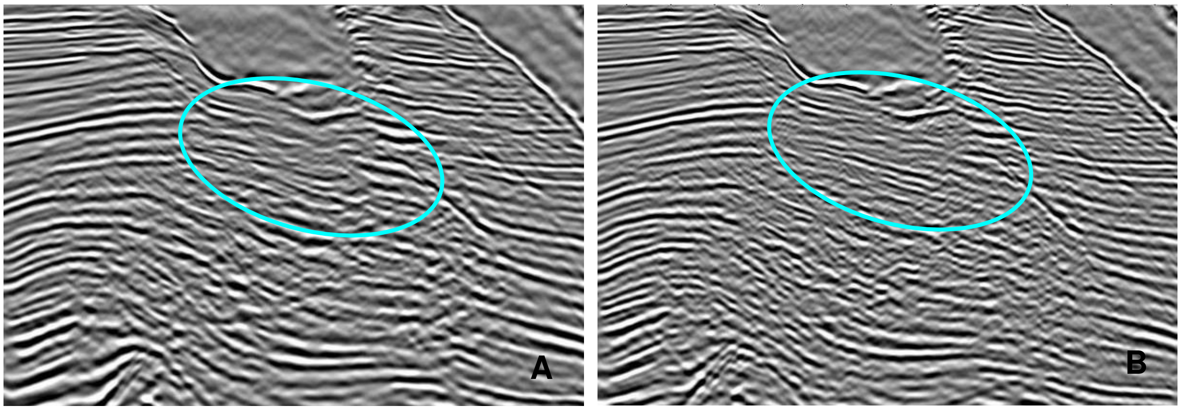

Figure 4: *RTM images: A) Using initial subsalt velocity model; B) Using updated subsalt velocity model*

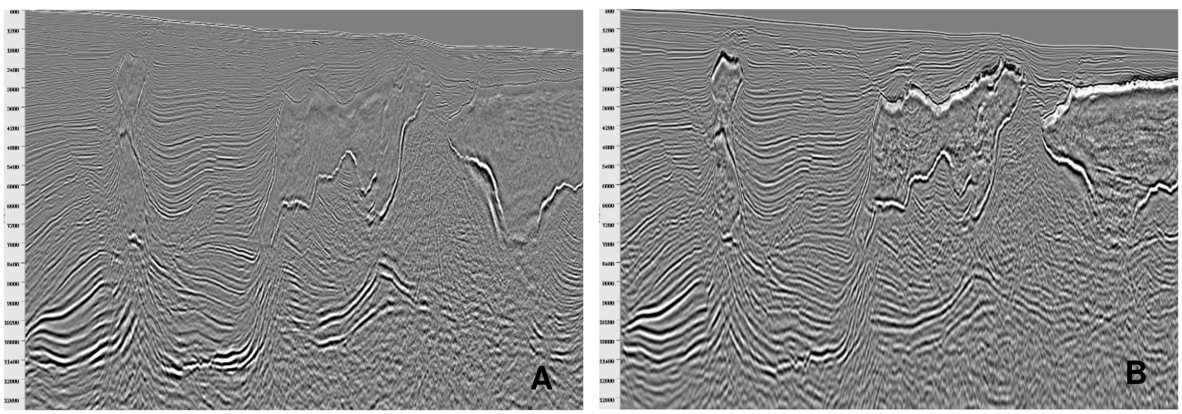

Figure 5: *A) NAZ VTI Kirchhoff image; B) WAZ VTI Kirchhoff image*

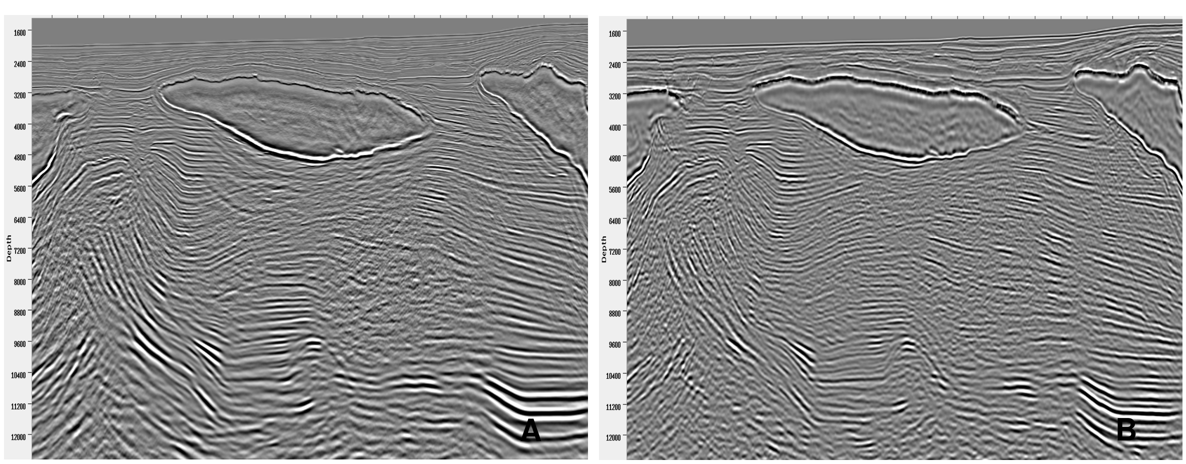

Figure 6: *A) WAZ VTI Kirchhoff image; B) WAZ VTI RTM image*

EDITED REFERENCES

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