Validation of WAZ time processing and depth imaging optimization using reverse time migration (RTM)

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Abstract

We propose a paradigm shift from the conventional way of validating time processing sequences and optimizing seismic depth images using data acquired with wide azimuth (WAZ) geometries.

For this purpose, we elected to use RTM (Reverse Time Migration) to validate key WAZ time processing steps such as: (1) designature and de-bubble, (2) noise attenuation and (3) demultiple. The result is a data set that allows us to generate high quality images in the depth domain.

During the depth imaging stages, the validation steps continue through depth velocity model building using intermediate RTM images. We propose and demonstrate a methodology where we exploit the availability of incidence angle and azimuth sectored common image gathers (ADCIG – angle domain common image gathers) to generate optimal seismic images using post-migration filtering, scaling and optimum stacking procedures.

Introduction

Processing seismic data collected with wide azimuth (WAZ) geometries in geologically complex areas presents significant challenges for time domain processing prior to depth imaging. Typically, unmigrated events that correspond to intricate geological structures with large velocity contrasts are difficult to evaluate in the time domain. Their associated scattering and complex ray paths call for pre-stack depth migrations (PSDM) to approximately position events in the depth domain. Therefore, the validation of the WAZ time processing sequence is best performed in the depth domain. For this purpose, we use RTM (Reverse Time Migration) as the PSDM method to validate key time processing steps such as: (1) designature and de-bubble, (2) noise attenuation and (3) demultiple. The result is a higher quality data set properly conditioned for depth imaging.

Why using RTM? Reverse time migration (RTM) is currently the preferred wave-equation method in the industry for generating high quality depth images in complex geologic areas. RTM is typically performed taking into account the anisotropic effects in the velocity field, in order to provide much improved and accurate seismic images in the depth domain.

RTM is a two-way wave equation shot-based prestack depth migration. It uses forward (source) and backward (receiver) propagated wavefields and an imaging condition to produce the image in depth. Throughout this paper, a pseudo analytical implementation of RTM (Crawley et al., 2010) was used to generate the required data for the WAZ time processing validations and optimizing the final subsurface depth images. Since RTM is a shot migration, single shots are input to produce migrated images for each shot independently, therefore making the algorithm suitable for WAZ (Wide-Azimuth) seismic survey designs. The accumulation of all images for all shots produces the stacked images in depth.

Routinely, these final stacked images are post-processed with filtering (denoise) and scaling techniques to reduce energy not belonging to the desired image, which should be related to the structural geologic model. Sometimes, these post-processing techniques are not fully effective and the stacked migrated image is still not optimum for a final interpretation.

Optimal depth images for structural interpretation are better obtained using incidence angle and azimuth sectored gathers (ADCIG). These gathers are routinely output for data collected with WAZ geometries. The ADCIG's provide the opportunity to apply filtering (denoise) and scaling. In addition, the ADCIG's are also stacked using a self weighted stacking (SWS) method which enhances the subsurface illumination in the final image due to the combination of incidence angles and azimuths for a single image point.

Validation of the WAZ time processing sequence

The proposed workflow to validate the key WAZ time processing steps is shown in Figure 1. The flow chart illustrates the role of PSDM imaging using RTM to perform systematic quality controls at the image level in depth. This implies that to pass a time processing step, the validation is done in two steps; one in the time domain and a second one in the depth domain. There are cases when the time domain results appear optimum, however, when building the seismic image in depth, residuals may still appear indicating the need to review and/or change the time domain processing parameters for the step under analysis.

In areas characterized by complex geology where high-velocity bodies such as salt, carbonates, basalt, etc. are present, the effective removal of the source signature and the bubble effects is imperative. The high acoustic

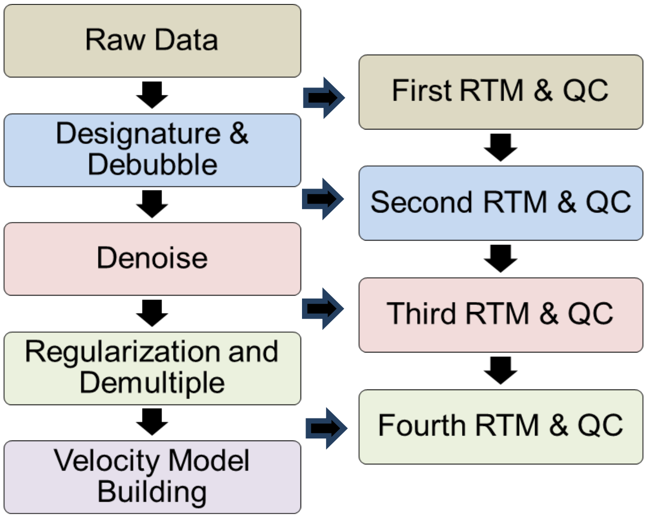

Figure 1: Work flow for a systematic approach to quality control of key WAZ 3D time processing steps using depth images generated with RTM.

contrast between sediments (e.g. clastics) and salt or carbonates or basalt challenges the effectiveness of the designature and debubble processes. Source signature and bubble residuals may still appear in the final image as the PSDM algorithms will, in general, emphasize these residuals not otherwise clearly observed in the time domain processing QC's.

Figure 2-A depicts a seismic migrated image generated with a 20Hz isotropic Reverse Time Migration (RTM) using the sediment flood velocity model and with designature and debubble applied. The top of salt (TOS) reflection is well defined and allows the interpreter for an accurate TOS picking.

Figure 2-B shows the same sub-line as that shown in panel A but with denoise applied. The types of noise attenuated in this step are those known as swell noise, seismic interference and other typical marine environment seismic noises. It is apparent that the noise removed does not appear significant and this is due in part because the RTM was performed at 20Hz. Besides, some other noise residuals are also attenuated during migration by destructive interference.

Finally, Figure 2-C shows the results of RTM but after the application of true azimuth (TA) 3D SRME for this Wide Azimuth (WAZ) data. If we compare panel B with C, it is evident that the surface multiples appearing clearly inside the salt bodies are effectively attenuated after TA 3D SRME followed by RTM. RTM emerges as a good diagnostic tool for demultiple.

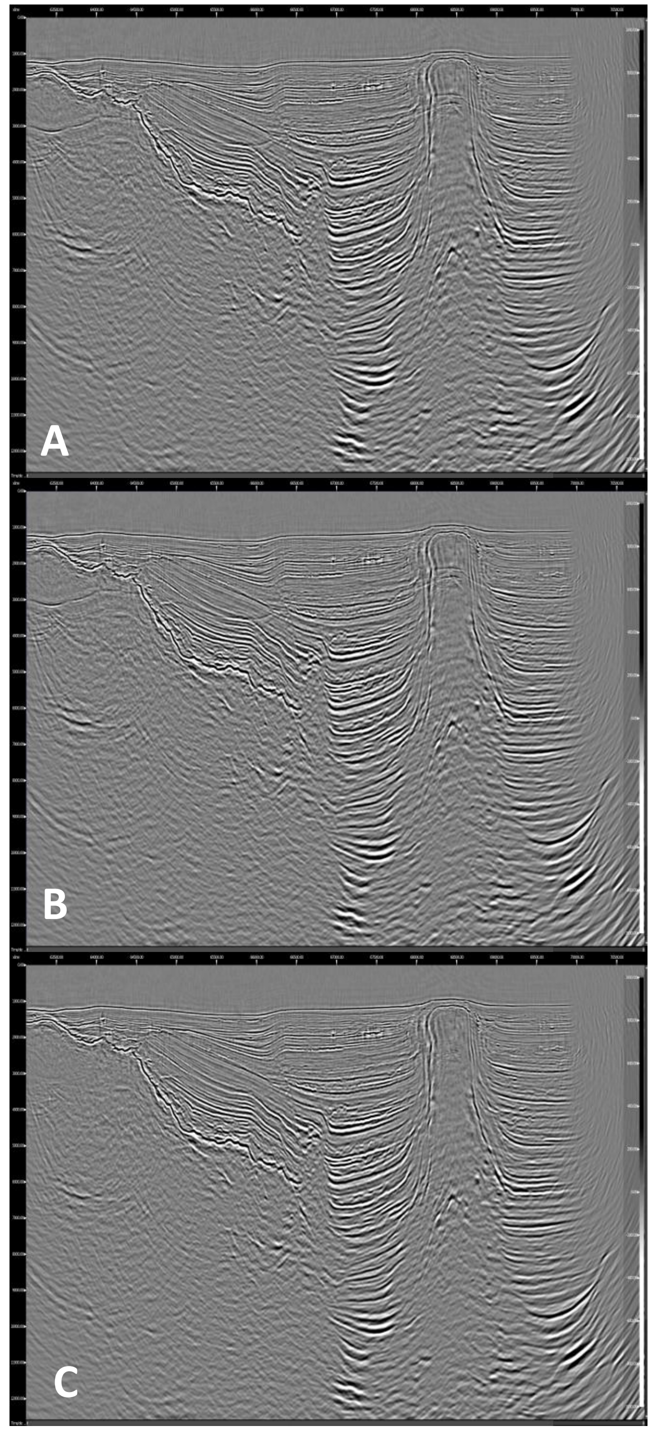

Figure 2: Seismic depth images obtained with RTM after: (A) designature & debubble; (B) denoise; and (C) TA 3D SRME. All RTM's were isotropic and used the sediment flood velocity model.

Optimization of seismic depth images using RTM incidence angle and azimuth sectored gathers (ADCIG's)

For NAZ geometries, the TTI RTM algorithm is capable of outputting incidence angle common image gathers. However, for WAZ and FAZ acquisition geometries, the richer azimuthal sampling can be used to output incidence angle and azimuth sectored gathers (ADCIG's).

The availability of incidence angle and azimuth sectored information at all image locations, not only provides the opportunity to perform thorough quality control of the migration velocity models, but also the chance to optimally remove unwanted energy from the final image such as: evanescent energy, migration artifacts, remnant noise from time-processing and improve the subsurface illumination using optimum weighting stacking.

Here we propose and demonstrate a workflow where we apply the following systematic approach:

(1) Carefully designing and applying a pre-migration mute to the input shot gathers.
(2) Migration of shots using TTI RTM.
(3) Initial denoise of the migrated incidence angle and azimuth sectored (ADCIG's).
(4) Optimally muting of the ADCIG's based on incidence angles.
(5) Use the self-weighting stacking (SWS) technique to effectively combine the information from the different incidence angles and azimuths into one image.
(6) Denoise of the resultant SWS stack.
(7) Finally, the application of amplitude compensation techniques to better balance the amplitudes of the final image.

While the pre-migration mute is typically used to mute out noise associated with the far offsets, the post-migration mute is typically designed taking into account the salt, basalt or carbonate geobodies, and the signal to noise patterns observed throughout the data. The SWS exploits the diversity of data existent in the different incidence angles and azimuth sectors as a function of depth and amplitudes. The resulting image is then subjected to combined filtering and amplitude balancing techniques to produce a final high-quality stacked image in depth. This seismic image should then be optimum for structural interpretation.

The effectiveness of the proposed workflow was validated through several field data tests from a marine WAZ (deep water) survey acquired in Gulf of Mexico (GOM).

Figures 3 and 4 show examples of the overall level of improvement between raw and enhanced images. Note that raw is defined as the image resulting from only outputting a stack during the migration (TTI RTM), while the enhanced image is the result of the workflow described above.

Image quality improvements are clearly observed below salt (Figure 3). The reduction of random and migration noise combined with the illumination enhancement provides an image that may be used for a more certain interpretation of the sub-salt sediments.

To validate that these improvements are achieved in 3D, we have displayed a depth slice at about 8000 meters (Figure 4). Clearly, the signal-to-noise improvements can be seen in 3D consistently providing a more interpretable and certain data set in depth.

Concluding remarks

We have introduced a pragmatic approach to perform quality control of the main 3D time processing steps for WAZ surveys using reverse time migration (RTM). This systematic approach is recommended for complex geology areas. Typically, in these complex areas, the time processing results at different steps may be considered optimum but when depth migration is performed, residuals of the source signature, bubble, noise or multiples may still be contaminating the RTM depth image. This may be unacceptable. By having the opportunity to QC the time processing steps with depth images, remedies to the problems detected in the RTM images may be found and corrected in the time domain before velocity model building begins. This ensures the best quality possible of the 3D time processing results.

After the TTI modeling building is accomplished, TTI RTM images can be significantly improved by taking advantage of not only denoising and carefully muting the incidence angle and azimuth sectored gathers (ADCIG's) prior to stack, but by optimally stacking azimuth gathers using self weighted stacking (SWS). Note that the use of the SWS technique can also be used to optimally stack incidence angle gathers in the case of overlapping NAZ surveys or other pre-stack images.

Reference

Crawley, Sean, et al., 2010, TTI reverse time migration using the pseudo-analytic method: The Leading Edge 29.11: 1378-1384.

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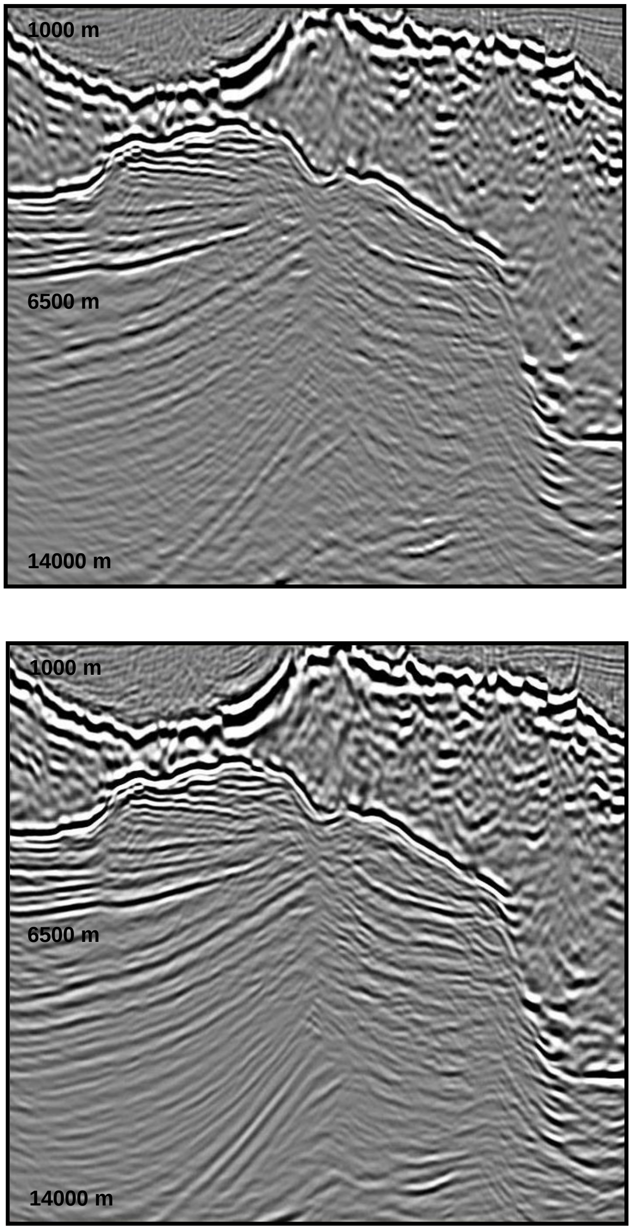

Figure 3: The top seismic image shows a raw RTM image, while the lower seismic image has been enhanced by the workflow described in this paper.

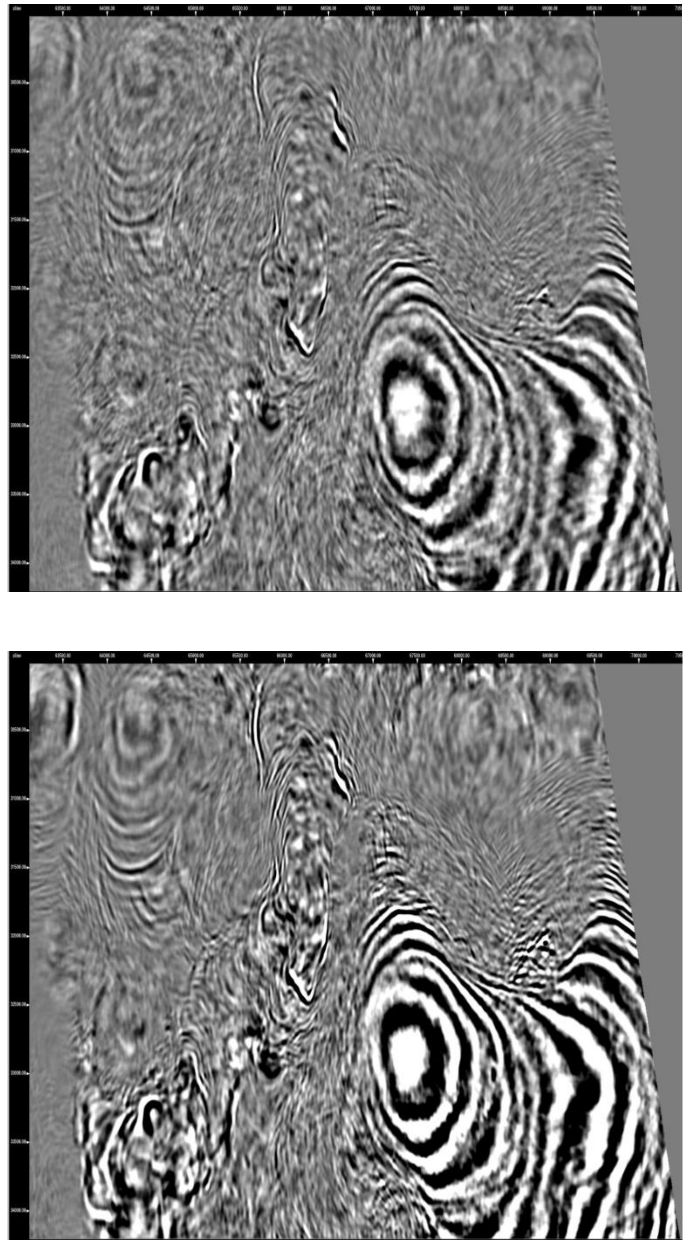

Figure 4: The top depth image slice shows the raw RTM depth-slice image through the pre-salt section, while to the bottom depth image slice has been enhanced by the workflow described in this paper. The image slice is at approximately 8000 meters depth.