Applications of Layer-Stripping RTM to Gulf of Mexico Imaging Projects

Cristina Reta-Tang, Jean Ji, Senren Liu and Bin Wang, TGS*

Summary

We have applied layer-stripping Reverse Time Migration (RTM) to several Gulf of Mexico (GOM) depth imaging projects. The key element of layer-stripping RTM is wavefield redatuming. By redatuming the wavefield below the subsurface, we dramatically increase the efficiency of RTM. Due to the complexity of salt bodies, GOM depth imaging projects typically require a large number of iterations of RTM runs in a top-down approach in order to build a more accurate salt velocity model. In some target areas, several salt geometry scenarios need to be tested before finalizing a salt model. Layer-stripping RTM is well-suited for building such complex salt models.

Introduction

RTM has become the standard imaging tool in many parts of the world, particularly in the Gulf of Mexico because of its high accuracy in modeling complex wave propagation. Not only is the final migration of depth projects run with RTM, but the entire salt model building process is carried out using RTM. In complex salt areas, due to rugose Top of Salt (TOS) and Base of Salt (BOS), it is necessary to test multiple interpretations and it is becoming a common practice to assess several salt geometry scenarios. In such complex salt areas, ray based migration algorithms are not sufficient to image BOS (Figure 1), and therefore RTM images from multiple models become an invaluable interpretation tool.

RTM is a two way wave-equation based algorithm with no steep-dip approximation and is capable of handling multi-pathing energy, thus imaging sharp velocity contrasts. Around salt overhangs and areas with multiple salt bodies in close proximity, RTM produces better images of event terminations against steeply dipping salt flanks. However, RTM is still an expensive tool, especially when used to image large surveys (more than 100 OCS blocks or 2,300 km^2) or when imaging with multiple velocity model scenarios. The cost can increase even more, by a factor of three when Tilted Transverse Isotropic (TTI) imaging is used instead of Vertically Transverse Isotropic (VTI) imaging.

In order to reduce cost and turn around time, we employed layer-stripping RTM (Wang et al., 2011) to several Gulf of Mexico surveys. The idea is to run RTM to a certain depth (z1) and save the source and receiver wavefields at z1 at every time step. After the RTM is completed down to z1, the saved source and receiver wavefields are used as input to run RTM for deeper sections. The process can be repeated for several regions. Because redatuming allows changing of the migration grid, migration aperture or velocity model below the datum, this methodology can save time, memory and disk space (Guan et al., 2009). This methodology also makes imaging with multiple salt geometry scenarios affordable.

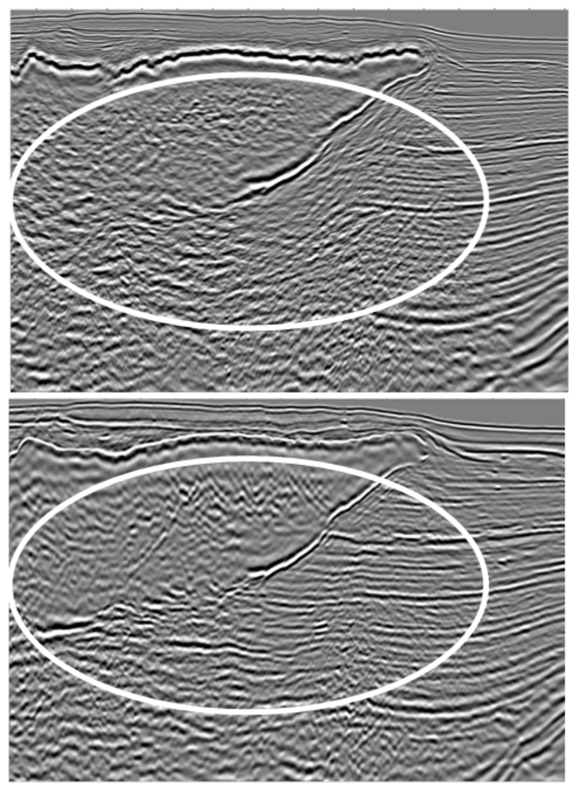

Figure 1: Ray tracing migration algorithms like Kirchhoff (top) are not sufficient to image complex salt areas. RTM (bottom) produces clearer subsalt images and the base of salt is better defined.

Method

We normally encounter the following limitations with the RTM runs:

- The RTM computational cell size is determined by the the maximum frequency and the minimum velocity in the model. Smaller velocities require smaller cell sizes dx, dy and dz consequently the number of grid points in the computational model will increase. A large number of grid points in the computational model will increase the memory and the disk space requirements to store the source and receiver wavefield snapshots, thus the RTM cost will increase.

- The size of the cells affects the frequencies to image. A large cell size limits the high frequencies to be imaged properly, though the memory and space requirements decrease because of a smaller total number of computational grid points.

To overcome these limitations we use the layer-stripping methodology.

Figure 2 schematically shows the steps used by this technique. Depending on the complexity of the velocity model, the model can be divided into two or more layers. RTM is run for the first layer and the source and receiver wavefields are recorded at a certain depth. The maximum depth for the first layer is smaller than the entire model, and consequently the number of computational grid points is smaller. At this stage, the source and receiver wavefields can be saved at the bottom of the first layer and the saved redatumed wavefields can then be used to run RTM for the second layer. When running the second layer RTM, the model size is reduced. More importantly, the computational grid size can be made larger without introducing dispersion noise because the minimum velocity is higher at depth (assuming velocity is increasing with depth) and because the seismic frequency is typically lower at depth. Thus, the reduction in the computational grid point numbers for each layer, compared to the entire model, makes the memory and disk space requirements feasible for large projects.

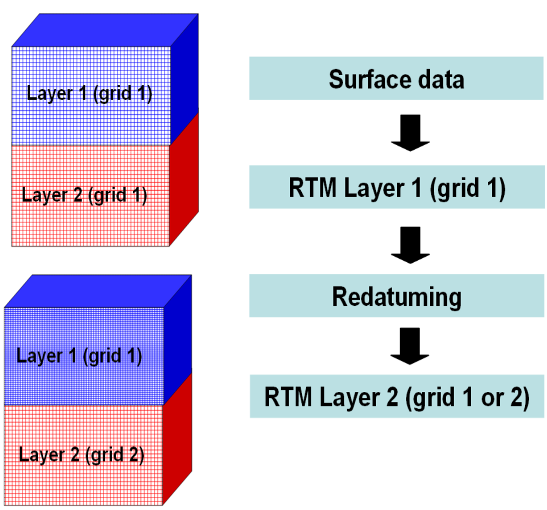

Figure 2: The velocity models are schematically represented on the left and a flow chart for layer-stripping RTM on the right

Because the layer-stripping methodology allows a change in cell size and aperture for each layer, a smaller cell size in the shallow section can be used to preserve high frequencies. The total computational grid numbers can be kept to a manageable level in each layer in terms of memory and disk space by appropriately controlling the thickness and the aperture. The aperture requirement to image relatively flat sediments above salt is normally smaller than the aperture required to image steeply dipping salt flanks.

Another advantage of the layer-stripping RTM methodology outlined above is that it enables us to test several velocity model building scenarios as an aid to interpretation. For example, the models in Figure 3 share the same first layer velocity model allowing one run of RTM. At the bottom of the first layer the source and receiver wavefields are stored (redatumed). Later, RTM is run simultaneously for different velocity models using the redatumed wavefield saved at the bottom of the first layer instead of the source and receiver wavefields from the surface. To make layer-stripping RTM practical, we resolved the well-known issue of 3D data explosion problem for wavefield redatuming by data compression (Wang et al., 2011).

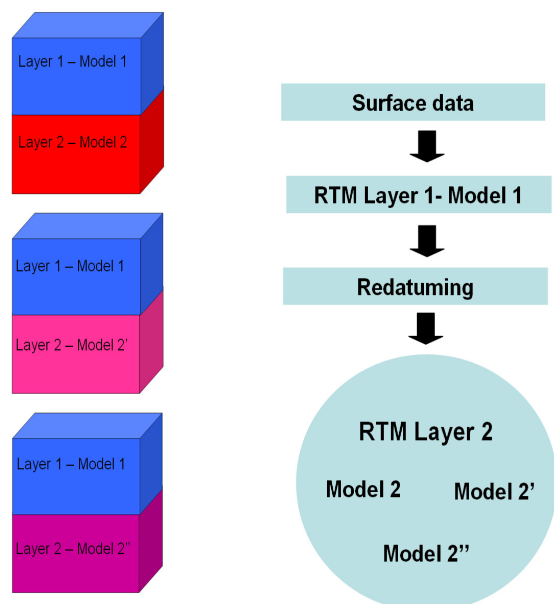

Figure 3: Layer-stripping RTM workflow chart for multiple model testing

Data Examples

To test the fidelity of the images obtained by layer-stipping RTM, we applied conventional and layer-stripping RTM to two perpendicular WAZ surveys in the Mississippi Canyon area of the GOM and compared the results. The orthogonal WAZ surveys were migrated down to 7000 m and we saved the redatumed wavefield at 6000 m depth using surface input data. For the deep part, the layer-stripping RTM was run from the redatumed surface (6000 m) to the end of the model. Figure 4 compares the images obtained by conventional and layer-stripping RTMs. Both images are very comparable indicating no loss in quality with this methodology.

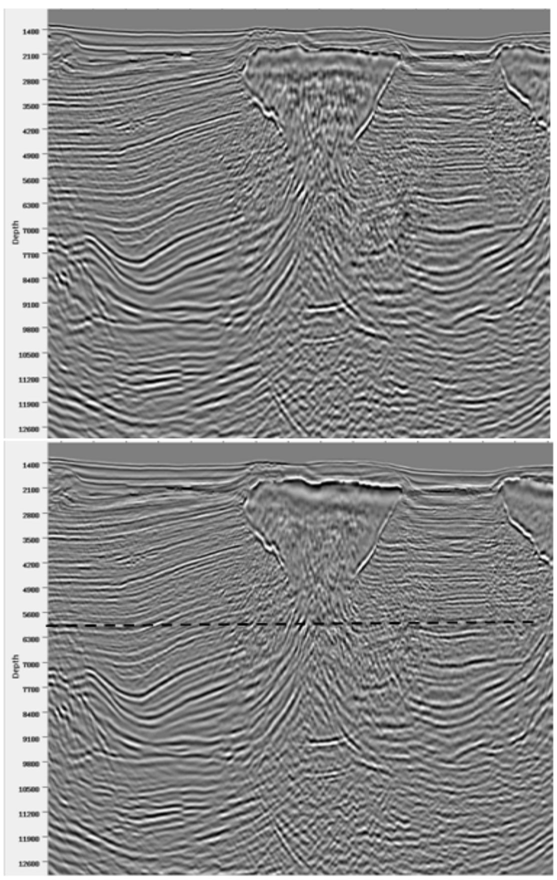

Figure 4: Conventional RTM on the top, layer-stripping RTM on the bottom. The dotted lines indicates the redatuming surface

The layer-stripping technique is particularly useful when imaging large multi-client surveys (approximately 300-700 OCS blocks) due to its efficiency. The computational cost can be reduced by changing the computational grid at the redatuming surface. This idea was applied to a large NAZ survey in the Gulf of Mexico. For benchmark purposes, regular RTM was run using dz=20 m (Figure 5a) and dz=30 m (Figure 5b). Then layer-stripping RTM was applied to the entire survey. The runtimes were significantly improved without compromising the image quality (Figure 5c).

The layer-stripping RTM is best suited for the velocity model building phase. When the velocity model is updated in a top-down approach, several migrations and interpretations for TOS and BOS pairs are run. In between these migration iterations, the source and receiver wavefields stored at a shallow datum are used repeatedly for many different models.

As exploration moves to very complex subsalt areas, correct interpretation of the base of salt is crucial for good subsalt image quality. Figure 6 shows a typical salt velocity model in the GOM. The data is from the Stanley survey in the Green Canyon/Walker Ridge area. The objective of this project was to test the effect of the thickness of the salt on the continuity of the subsalt sediments. The model was divided into two layers, the first layer included salt but the base of the layer was above the base of salt. Several models were created by changing the velocity model inside the second layer as shown in Figure 7. The thickness of the salt and shape of the base of salt were different for each model as shown on the left side of Figure 7. Redatuming of the seismic data from the surface to the subsurface datum (annotated as A in the Figure 6) allowed us to quickly test several velocity models in the deeper section. The right side of Figure 7 shows the RTM images corresponding to each model generated by using the redatumed wavefield at the subsurface position A. The bottom left image is more focused and consistent with regional geology.

Conclusions

We have reduced run times, memory and disk space requirements by applying the layer-stripping RTM methodology, and the images produced are comparable to the images generated by conventional RTM. Redatuming of the wavefield is a key component of this methodology. Because of the improved efficiency, it becomes feasible to image large surveys with RTM during model building and in the final migration.

Acknowledgments

The authors would like to thank their colleagues at TGS, in particular Kwangjin Yoon, Sang Suh, James Cai, Alex Yeh, and Xinyi Sun for their contributions. We also thank Duryodhan Epili, Simon Baldock, Chuck Mason and Laurie Geiger for reviewing the manuscript. The authors wish to thank TGS management for support and release of the material for publication.

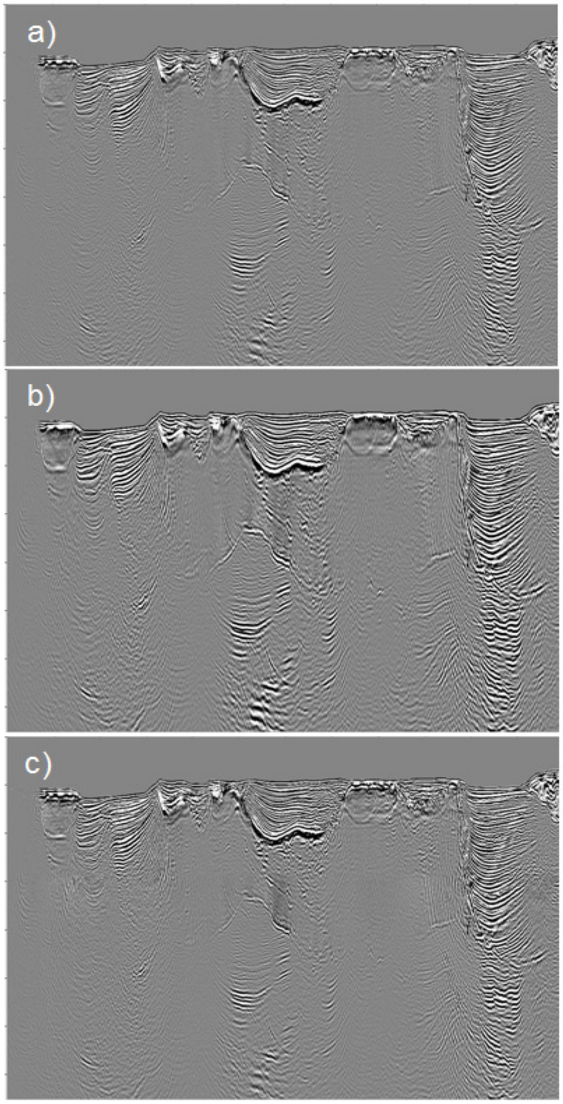

Figure 5: a) regular RTM, dz=20 m; b) regular RTM, dz=30 m ; c) layer-stripping RTM using 20 m and 30 m grid

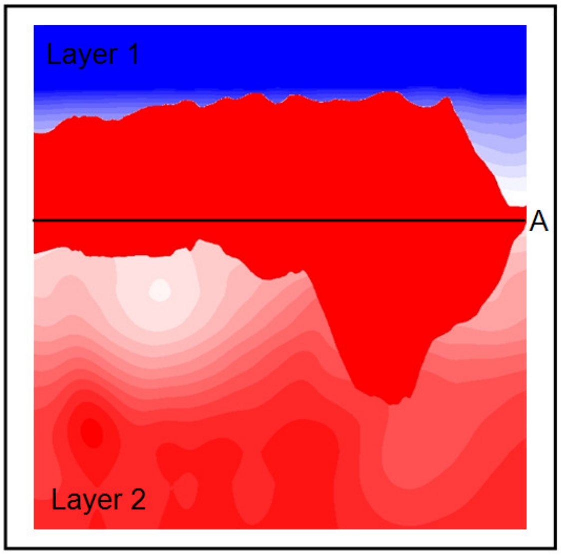

Figure 6: Initial salt velocity model. Different salt geometries will be tested from surface A

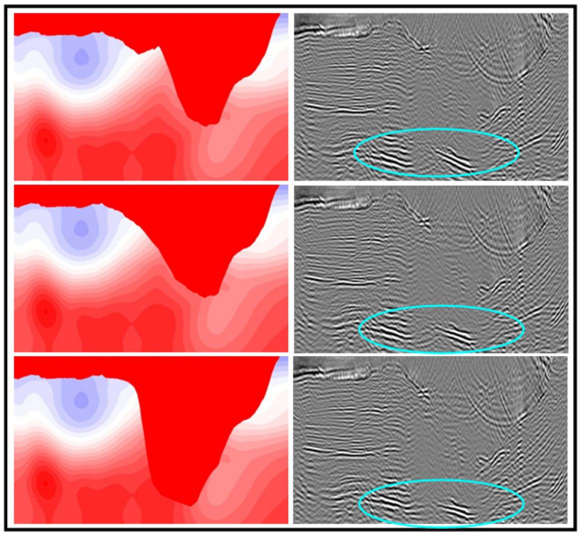

Figure 7: Left column shows different salt interpretaions and velocity models. Right column shows the corresponding layer-stripping RTM using the velocity models on the left

EDITED REFERENCES

Note: This reference list is a copy-edited version of the reference list submitted by the author. Reference lists for the 2011 SEG Technical Program Expanded Abstracts have been copy edited so that references provided with the online metadata for each paper will achieve a high degree of linking to cited sources that appear on the Web.

REFERENCES

Guan, H., Y. Kim, J. Ji, K. Yoon, B. Wang, W. Xu, and Z. Li, 2009, Multistep reverse time migration: The Leading Edge, **28**, 442–447, doi:10.1190/1.3112762.

Wang, B., J. Ji, K. Yoon, J. Cai, W. Whiteside, C. Mason, and Z. Li, 2011, Layer-stripping RTM based on wavefield redatuming: SEG, Expanded Abstracts, submitted.