Seismic depth imaging from high to low signal: a case history

August Lau and Chuan Yin, Apache Corporation, Dhananjay Tiwari, Zhiqiang Guo, Gary Rodriguez, and Jean Ji, TGS*

Summary

The ultimate goal for seismic depth imaging is to find new hydrocarbon prospects or improve existing ones. High quality seismic data and an accurate velocity model are the main drivers for good imaging. Prospects may be identified on seismic data in areas which can range from high to low signal. Roughly speaking, prospects generated for shallow targets will be on good signal data and prospects for deeper targets will be in low signal areas, with the signal strength somewhere in between for the mid-range depths.

Different imaging approaches, including migration algorithms and velocity model building techniques, are needed for the different situations of varying geology and signal-to-noise ratios.
In areas of high signal, tomography is useful for refining the velocities for three-way (e.g. fault traps) or four-way depth closures. Where signal-to-noise is lower, more modern tools will be required.

Areas of medium signal might include salt overhangs and fold-and-thrust belts, where we might want to define closure under a high angle thrust fault. These areas could benefit from Reverse Time Migration (RTM) based Delayed Imaging Time (DIT) scans. For deeper targets where the signal is often low, efficient RTM layer stripping can be very effective for improving the imaging of plays below salt or beneath a detachment or unconformity.

We are presenting a case study showing improvement in the overall imaging in terms of fault closure, subsalt sediments truncating against the salt flanks, and better focusing around the salt overhang in an area of the Gulf of Mexico (GOM). This paper will demonstrate the benefit of tomography for sediment velocity model building and updating for depth imaging, along with the improvements gained by using RTM based DIT scans and layer stripping RTM.

Introduction

In terms of the signal-to-noise ratio of the seismic data, the imaging challenges can be broadly categorized into three major situations: 1) imaging in areas with a good signal-to-noise ratio, for example the shallow, thick sediment zones of most of the GOM area; 2) imaging in areas with a moderate signal-to-noise ratio; and 3) imaging in areas with a very low signal-to-noise ratio which we encounter in deeper zones which are surrounded by multiple, complex salt bodies. These different scenarios require different techniques for building an accurate velocity model which can be used to produce high quality depth imaging.

Reflection based tomography is the industry's current standard practice for updating the sediment velocity model. In areas with a good signal to noise ratio, consistent residual move-out (RMO) can be picked on the migrated common image gathers for input to the tomography. Therefore for most of the GOM areas reflection based tomography is still the standard tool to optimize the velocity model by several iterations in the thick sediment zones. The ray based imaging algorithms like Kirchhoff and beam migration are good enough for imaging the steep deeps and fault closures with moderate velocity contrast. However, in complex salt geometry areas the ray based algorithms are not sufficient for imaging the subsalt structures, due to the high velocity contrast between the low velocity sediment and high velocity salt.

For the inversion part, the theoretical result using L2 (e.g. tomography) is Parseval's theorem which states that L2 (time) = L2 (frequency). Error exists in data fitting the L2 norm in the time domain which is equivalent to error in the frequency domain. The geological interpretation of Parseval's theorem is that we have error in every frequency/wavenumber. All L2 inversion has non-geologic sinusoids spatially because of errors in the low wavenumber component (Lau et al., 2012). Therefore when the tomography stops converging we should use other tools such as velocity scanning to gain better confidence in the imaging.

RTM is based on the two-way wave equation. Compared to other imaging algorithms, it uses a more accurate wave propagator and is able to handle high-velocity contrast boundaries and complex wave modes such as multi-pathing, turning and prismatic waves. In complex salt geometry regions, RTM is the standard imaging tool, as it can image the steep deep salt flanks and overhangs found on many salt bodies. In spite of all these benefits of RTM over the one-way wave equation and ray-based algorithms, the end product from the RTM still heavily depends on the accuracy of the velocity model and the quality of the seismic data used for the migration.
In subsalt regions and around zones with multiple salt bodies, there is often not enough signal on the common image gathers for the residual move-out picking. In this scenario, ray-based tomography has very little useful information around the salt overhangs and subsalt to provide accurate velocity updates. Therefore, for most of the cases we end up using inferior quality velocities beneath the salt for the RTM. Ultimately, this results in poorly resolved subsalt imaging even using an accurate program like the RTM.
To get improved imaging of subsalt areas and complex overhangs, we have used RTM-based DIT scans (Wang et al., 2009) in this area. The composite images from the full

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cube of DIT scans can be used to aid the interpretation of salt structure and subsalt events. The RTM-based DIT scan technique could also be a good technology used in fold-and- thrust belt areas.
Once we refine the model/salt interpretation with the help of a full cube of DIT scans, the mini-basin areas among the many salt bodies and the deeper subsalt areas can be further improved using layer stripping RTM (Wang et al., 2011) for velocity perturbation scans (Lau et al., 2008). We will first describe briefly about the model building approach used for this area followed by RTM based DIT scans and layer-stripping RTM velocity perturbation scans with some real data examples.

Imaging in high signal areas using Tomography

Tomography is the routine process for optimizing the sediment velocity model. Faster convergence of the velocity model through tomography needs a good initial velocity model. The initial isotropic velocity model for this area was derived using the smoothed final stacking velocities. The data was then migrated with the isotropic model. Common image gathers and the isotropic model were analyzed at several check-shot locations to derive the delta and epsilon fields which were then used to build the initial anisotropic (VTI) velocity model (Cai et al., 2009).

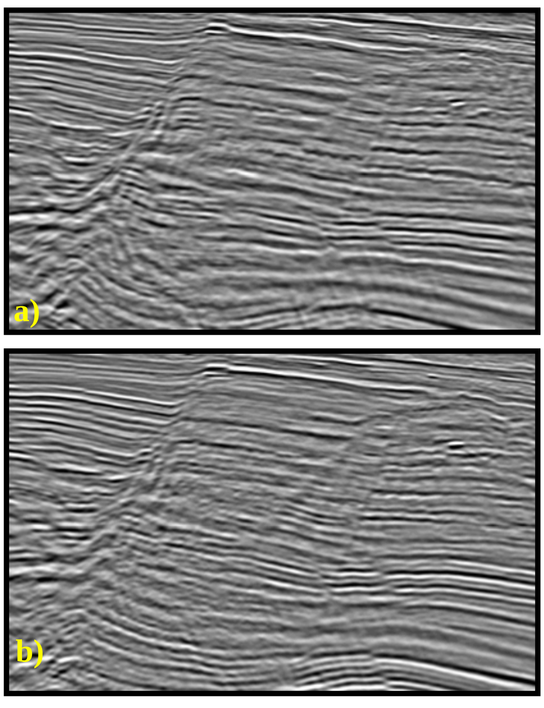

Figure1: Kirchhoff Pre-stack depth migration stacks (a) With initial velocity model (b) Using final sediment velocity model.

Four iterations of grid-based tomography were run to optimize the velocity model within the sediment zones. Grid-based tomography is an efficient tool for updating the model as long as consistent RMO and geologically plausible dips are fed into the tomographic inversion engine.

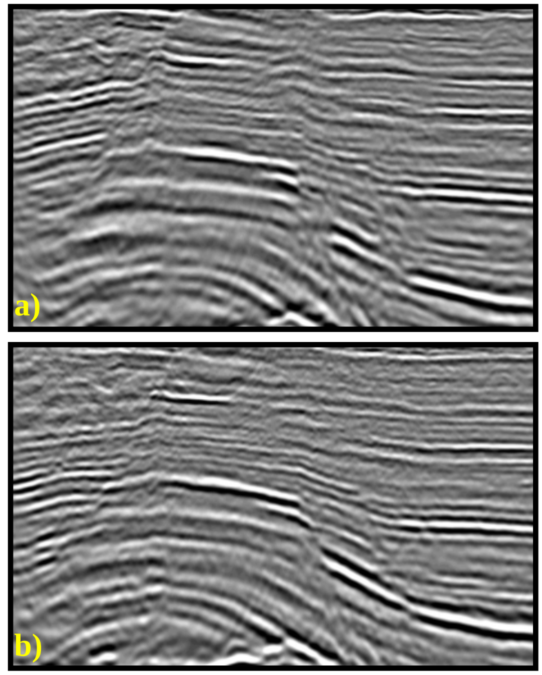

Figure2: Kirchhoff Pre-stack depth migration stack (a) With initial velocity model (b) Using final sediment velocity model

Figures 1 and 2 show the a comparison of the Pre-stack Depth Migration (PSDM) images using the initial velocity model and final tomographically updated velocity model in the sediment areas. These pictures clearly demonstrate the strength of tomography to resolve the detailed velocity anomalies in the model which helps place the fault planes and the sediment packages at correct vertical and lateral positions with improved fault plane sharpness and closure.

Imaging in medium signal areas using DIT scans

At mid-depth regions with a moderate signal to noise ratio, tomography is not able to bring the required details into the model due to limited quality RMO picks and dip scans. Although RTM is capable of handling complex wave propagation associated with the complications of the salt geometry, an accurate velocity model is needed.

In the absence of an optimized velocity model we may need an imaging condition within the RTM engine which allows an indirect perturbation of the velocity model to improve

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imaging beneath complex salt and overhung areas. DIT scans utilize a non-zero-time imaging condition.By applying several non-zero-time imaging conditions, multiple migration images can be produced from a single migration (DeVeris and Berkhout, 1984; Wang et al., 1995, 1998, 2009; Sava and Fomel, 2006).

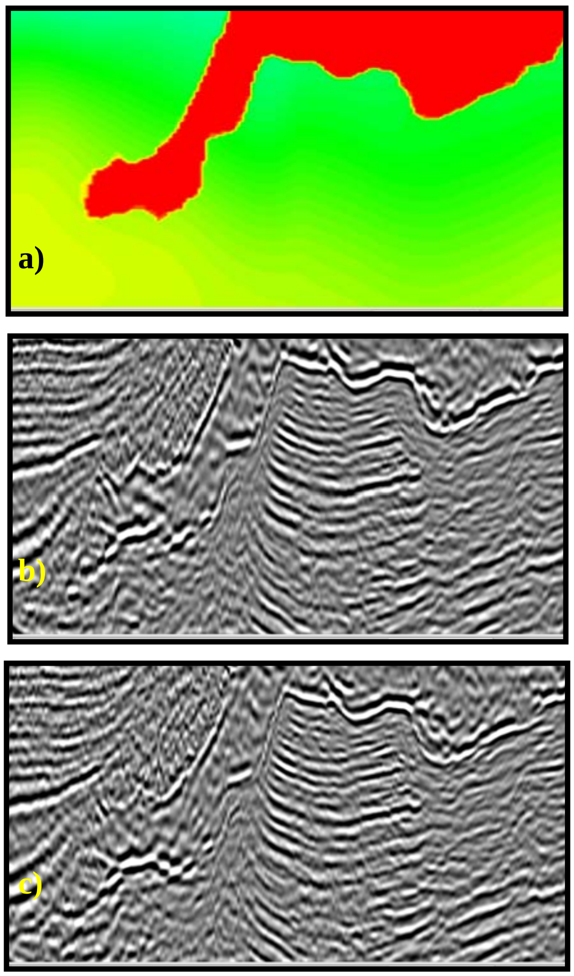

Figure3: DIT scans (a) velocity model (b) Regular RTM image (c) RTM image with delay time of negative 125 ms

DIT scans use an imaging delay time to simulate the velocity perturbation, and each scan image is a complete migration stacked image. Due to the stacking power, it is more suitable for areas with relatively poor signal to noise where pre-stack RMO is hard to pick.
The full DIT scan cube can be very helpful for imaging complex subsalt zones and sediment truncation against complex salt flanks, which could be hydrocarbon pay zones.
Figures 3 and 4 shows the DIT scan examples for two different lines. Clearly, the sediment truncation against the salt flank is improved using the negative delay of 125 ms as an imaging condition in the final step of RTM. Negative delays correspond to a decrease in the velocities; however positive delays denote an increase in the velocities.

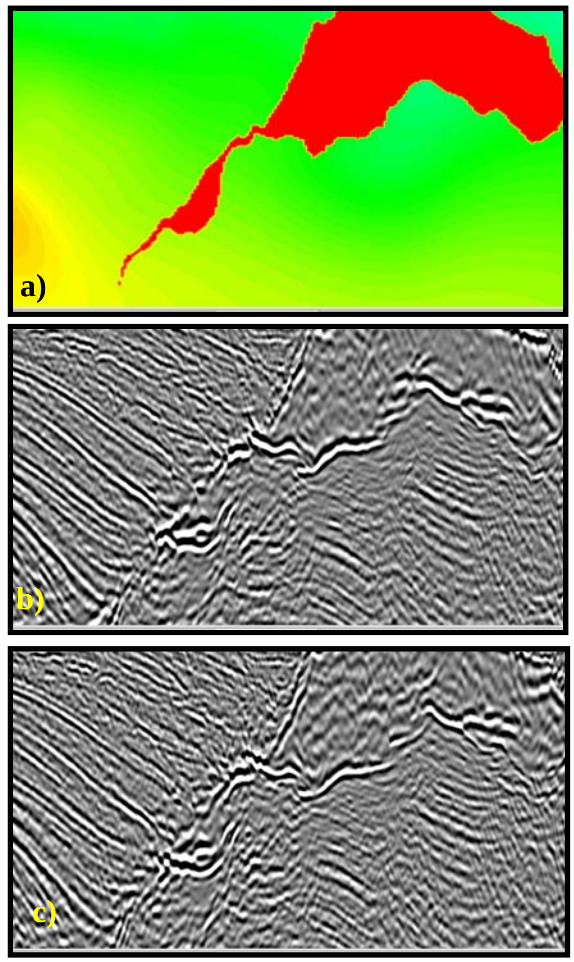

Figure4: DIT scans (a) velocity model (b) Regular RTM image (c) RTM image with delay time of negative 125 ms

DIT scans allow for an indirect perturbation in the overall model and therefore a stand-alone DIT scan volume could be used for interpreting complex overhangs and subsalt sediment regions.

Imaging in low signal areas using layer stripping RTM

RTM with perturbations of the velocity model beneath the salt is needed especially in deeper subsalt region where the

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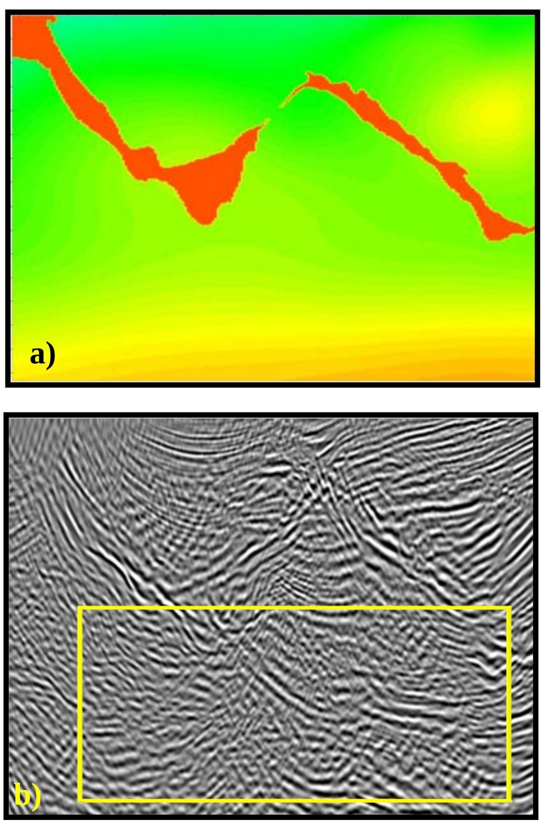
seismic signal is very low. RTM for salt geometry scenario testing is a very effective tool in terms of imaging but the cost is high to run a separate migration for each model. In order to utilize the benefit of running a subsalt velocity perturbation yet at a reasonable cost, we employed the layer stripping RTM methodology (Wang et al., 2011) in this area.

The methodology is to first run the RTM to a depth where we think that model is optimized enough to represent the sub-surface within the desired level of accuracy. Both the source and receiver wavefields are saved to disk down to that depth and then multiple velocity models are used for simultaneous RTM runs for the deeper portion. Running the RTM in this manner has multifold advantages. Firstly, smaller aperture can be used for the shallower run of RTM which reduces the computational cost. Secondly, for the deeper part of the RTM, an increased minimum velocity allows us to use a bigger computational grid size without introducing dispersion noise.

Figure 5 shows examples of sub-salt velocity scan using the layer stripping RTM. Velocity within the sub-salt perturbed and layer stripping RTM tools used for the faster turn-around time to get seismic imaging.



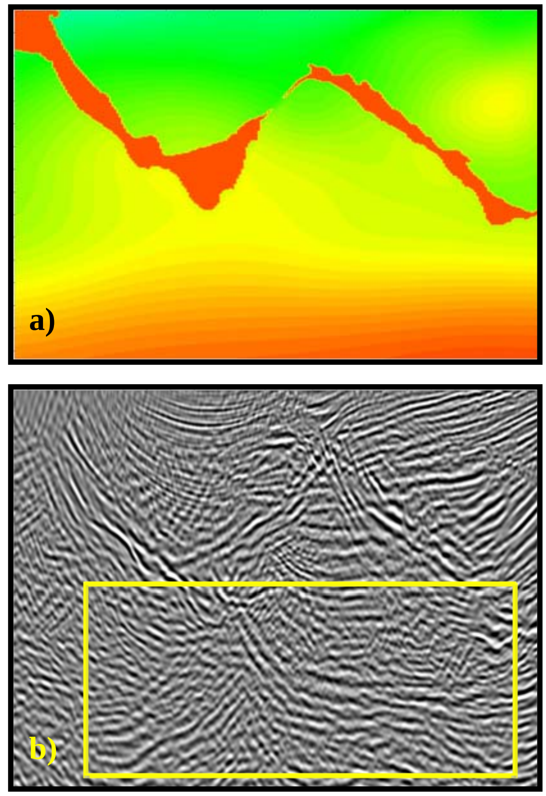


Figure 5 sub-salt velocity scan using layer stripping RTM.

Conclusions

We have demonstrated three approaches to seismic depth imaging in good signal to noise areas, medium signal to noise areas and low signal to noise areas, using tomography, RTM DIT scans, and velocity perturbation scans using layer stripping RTM, respectively. We have seen for 3D narrow azimuth seismic data, tomography is good for updating the model where the signal to noise ratio is of good quality. DIT scans are effective for imaging subsalt areas with moderate signal to noise ratios, as they allow indirect velocity perturbations in the model, while layer stripping RTM gives the benefit of subsalt scanning in a more efficient manner. The three methods could be classified broadly as an inversion method, velocity scan without re-migration and a velocity scan with re-migration.

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EDITED REFERENCES

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