



Application of Reverse Time Migration to Complex Imaging Problems

North Sea

By Paul A. Farmer and Ian F. Jones

Introduction

Historically, migration of seismic data has been performed with either integral or wavefield extrapolation methods. These two methods both have significant limitations that prevent effective imaging in some instances. In 2005 GXT commercially introduced RTM, a migration technique that overcame the limitations of these existing techniques. Since introducing RTM, GXT has used it effectively on dozens of projects spread throughout the world. This article will start by discussing the limitations of the existing techniques, discuss how RTM addresses these limitations and then show with synthetic and field examples the effectiveness of the RTM technique.

Migration Technologies

Standard shot-based one-way wavefield extrapolation (WE) preSDM techniques image the subsurface by continuing the source and receiver wavefields for each shot downward in depth. An image is subsequently formed by cross correlating these two wavefields at each depth level and each lateral position. Finally the partial images formed for all shots are summed to form the final image. One of the assumptions made in this technique is that the source and receiver wave fields only travel in one direction along the direction of extrapolation: forwards for the source wave-field, and backwards for the receiver or scattered wavefield.

In practice, each of these wave-fields will generally travel both up and down if the velocity model is complex or exhibits strong velocity gradients. Such complexities will produce turning (or diving) rays and multiples. Furthermore, approximations in the one-way wave equation extrapolation techniques usually limit the dips present in the final image to less than seventy degrees.

Steep dips, and turning rays are usually imaged using Kirchhoff techniques, but this technique fails to deliver acceptable images when either the source or receiver wavefields become sufficiently complex for multipathing of the wave fields to occur.

The RTM migration technique (Baysal et al, 1983) addresses all these issues by directly using the two-way acoustic wave equation without any approximations or assumptions. The source wavefield is propagated forward in time and the recorded receiver wavefield is propagated back in time. The latter back propagation of the receiver wavefield is the reason that the method is known as a reverse time migration or RTM for short. Because RTM propagates the wavefields using the exact acoustic wave equation it can image data through velocity structures of arbitrary complexity without error or dip limitations. RTM even has the potential to image multiples when the boundaries responsible for the multiple are present in the model.

Commercial Status

Until recently RTM was considered economically impracticable due to its high computational requirements. Recent advancements in computer science and computing capacity, both in terms of CPU speeds, storage capacity and highly efficient hardware infrastructure, have now made RTM commercially viable. GXT has run over 26 projects including, the Gulf of Mexico, Offshore West Africa, and the North Sea using the RTM technology. This technology is not limited to classic narrow azimuth towed streamer data, but can also be used with multi or wide azimuth towed streamer data as well as in OBC settings. GXT also has considerable experience in using RTM for VSP imaging. After having run this many projects, GXT has gained great understanding of how to manage projects so that they can be delivered within clients expected turn around time. GXT has now leveraged their experience in running final migrations with RTM so that this technology is included in the model building phase. While RTM has the potential to migrate all multiples, practice shows that if multiples can be profitably handled, then enhanced images of the subsurface will result. However, for multiples generated by interfaces not adequately described in the migration model, multiple suppression is still required. To this end, GXT has spent a great deal of time developing their 3D SRME anti-multiple tools, and has seen that the imaging results after it's application improved as would be expected.

Synthetic Example

The ability of RTM to effectively image complex structures is demonstrated on acoustic FD synthetic data. (These data were provided by BP and were first shown at the EAGE Paris model building workshop: Billette & Brandsburg-Dahl, 2005). Figure 1 shows the result of imaging the data using a one-way wave equation migration, and Figure 2, shows results of migrating this data using RTM. In the one-way image, we are unable to handle turning ray energy that illuminates the overhanging salt, and the steep portions of the salt stems are either not imaged (due to algorithmic dip limitation) or not illuminated by the acquisition. Steep dips, and the turning wave energy, as well as energy from other two-way ray paths, are handled by the RTM, producing a good image. The one-way migration examples shown in this paper were obtained using a split-step Fourier plus interpolation algorithm (SSFPI).

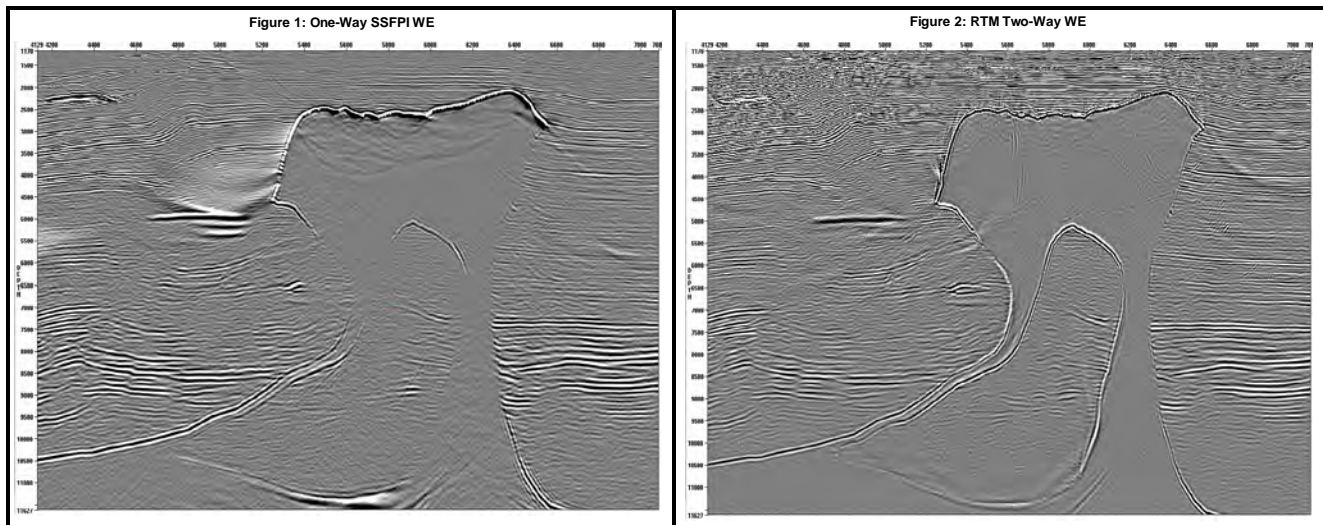


Figure 1) A subsalt image generated with an SSFPI one-way WE migration shows poor imaging of salt flanks and subsalt structures; Figure 2) A subsalt image generated with RTM technology shows significant improvement in imaging salt flanks, even beneath the salt. (input synthetic data courtesy of BP, imaging by GXT).

3D Field Data Example

In this section we consider the effectiveness of anisotropic 3D RTM on a classic mushroom shaped salt dome typical of parts of the North Sea. A commercial 3D WE project had recently been completed, so we had a 'final' 3D model available, as well as comparisons of the usual one-way WE and Kirchhoff images. Figures 3 and 4 respectively show the velocity-depth model and Kirchhoff preSDM result for crestal line 'D', where the deeper (sub-chalk) targets are not adequately imaged, due in part to multipathing issues.

As with any complex data, or in trying to understand the kinematics of a new algorithm, forward modeling tests are often instructive. With this in mind, we ran some 2D ray tracing through a model of a crestal line from this salt body. Our main interest with this was to ascertain what classes of energy may be involved in illuminating the steep salt flank events. In Figure 5 we show the ray trace results for events passing through the top salt, propagating as P waves, and illuminating the salt flanks. Figure 6 shows the corresponding ray paths for the PSSP arrivals. In Figure 7 we show ray paths for double bounces (prism waves) that reflect off both the salt flanks and the flat lying top Balder and top Chalk events. The predominant class of energy illuminating the salt flank seems to be the double bounce arrivals. In this case we were not able to unambiguously identify PSSP arrivals in the real data. Turning-ray energy was not present for these data, as the vertical velocity gradients in the overburden were slight, and included a significant velocity inversion at the mid-Miocene unconformity.

Using the conventionally derived final 3D velocity-depth model shown in figure 3, we ran an RTM, limiting the migration frequency to 17Hz. The results of the RTM clearly indicated the inadequacies of the conventional model building route, and we proceeded to attempt to refine the model based on iterative RTM model update. Figures 8 and 9 show respectively a one-way WE preSDM and corresponding RTM for crestal line 'A' (using the 'final' model

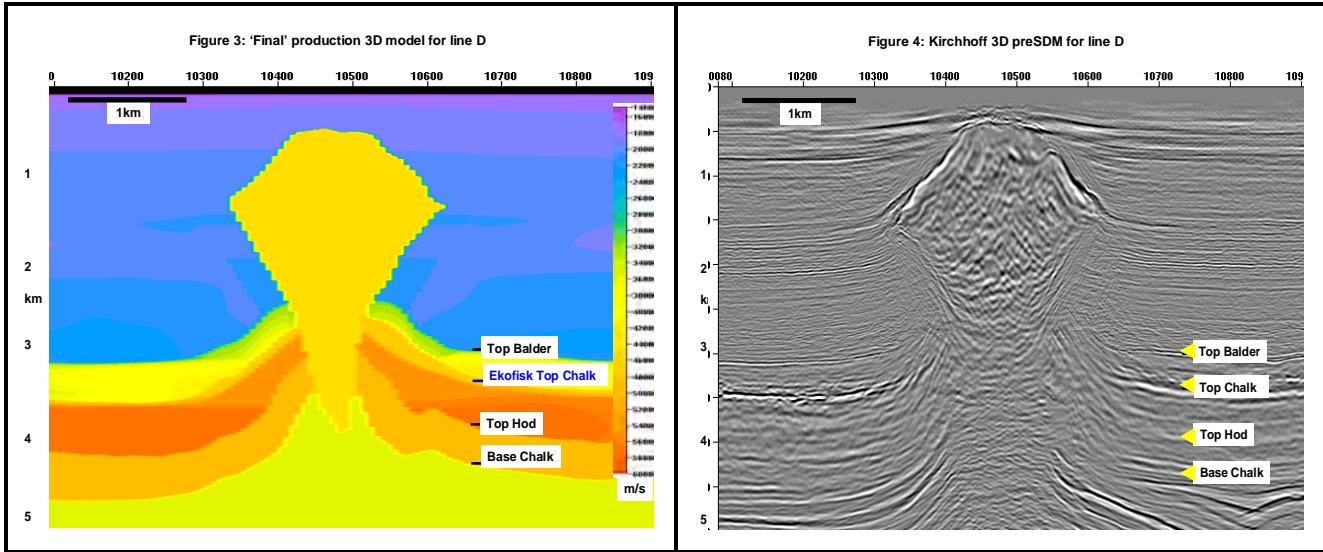


Figure 3) 'Final' production 3D model for line D.; Figure 4) Kirchhoff 3D preSDM for line D.

from the commercial project. It should be noted that as these images were archived during different stages of a now completed commercial project, that they differ slightly in terms of input and output trace spacing, wavelet processing, and final bandwidth. However, these differences will not have an impact on the conclusions drawn here.

We see from the RTM that we have very steep salt flank arrivals (perhaps from an upturned chalk interface). From the ray trace study (Jones, 2008), it was concluded that these steep events probably come from double-bounce illumination. The salt interpretation in this model, made on the basis of the WE results, looks like it is incorrect near the edges of the salt, especially on the right hand side (a salt proximity study was used to constrain the model to the left of the salt body). The RTM result indicates that the salt is probably a bit less wide, with near-vertical edges below a slight overhang. Also, the RTM result indicates that the top Balder and top Chalk events probably turn-up sharply to abut the salt, rather than 'rolling through' the model with a gentle anti-clinal shape, as was used in the production model.

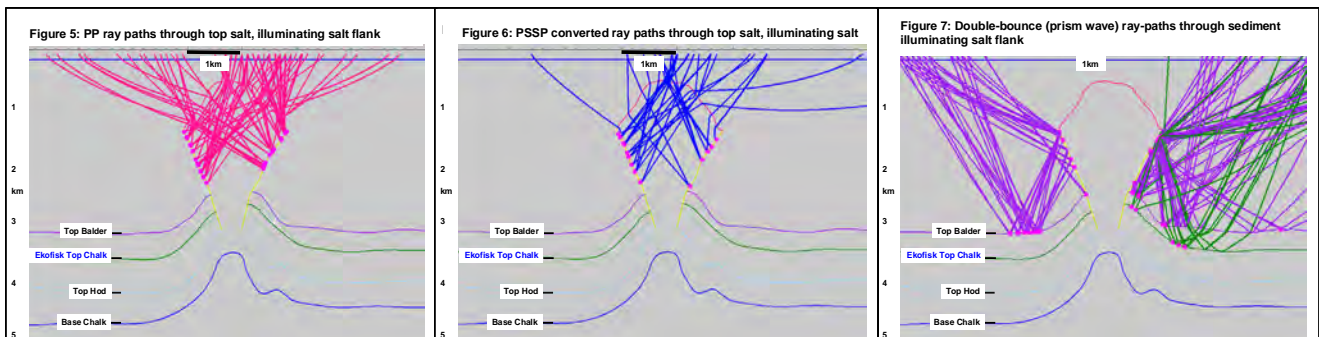


Figure 5) PP ray paths through top salt; Figure 6) PSSP ray paths; Figure 7) Double bounce arrivals illuminating steep flanks of structure.

Conclusions

Complex bodies such as salt domes are illuminated by many wave paths that cannot be imaged by conventional one-way propagators. Significant improvement can be achieved both in the model building and final migration by employing the two-way reverse time migration technique. It is the combination of model building and migration that is the key to successful imaging. Iterative application of RTM, using RTM angle gather tomography to update velocities, can be used to delineate salt geometries in areas where both Kirchhoff and one-way wave equation methods fail.

Subsequent imaging of the salt body shows enhancements to steep and overturned flanks, most likely illuminated by prism waves (double bounce arrivals). Errors in the velocity and anisotropy parameters will greatly influence the positions of near-vertical events, so misalignment of the vertical salt (or sediment) flanks seen here could be used to assist with model update.

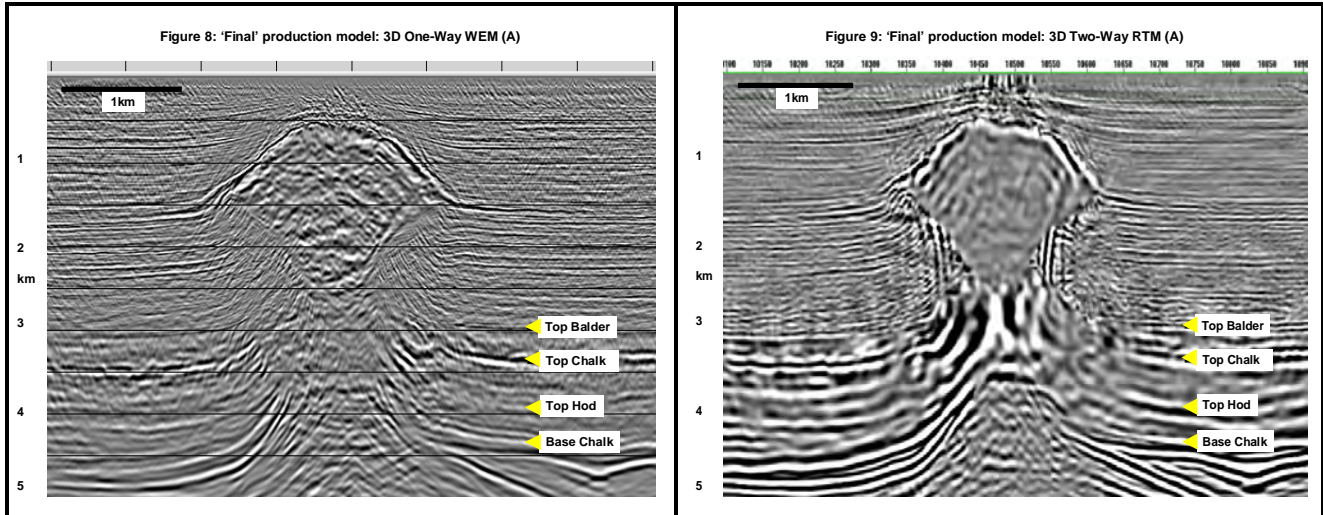


Figure 8) Low-pass filtered SSFPI WE preSDM from line A.; Figure 9) RTM for line A. Both images here have used the same 'final' production 3D velocity model.

References

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2910, 400 – 4th Avenue SW
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Canada
Tel: 403-263-9139
Fax: 403-263-9132

ION GX Technology
225 East 16th Avenue
Suite 1200
Denver, CO 80203
United States of America

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