RTM aids in imaging and MODEL ESTIMATION

By Paul Farmer, Zheng Zheng Zhou, and David Jones
ION GXT Imaging Services

The latest depth-imaging technology is gaining wider acceptance in the E&P industry.

The challenges of subsalt imaging are daunting. Salt structures are formed when salt sheets intrude into higher-density sediments deposited above them. The resulting domes, walls, pillows, ridges, and fountains are complex. They can be free-floating or remain attached to the base salt layer as irregular, mushroom-shaped bodies called diapirs. The current area of interest is in deep water, where complex salt bodies provide geoscientists with significant imaging challenges. These steeply dipping traps can be extremely prolific, capable of being drained with relatively few high-rate wells – ideal for high-cost deepwater environments.

Imaging reservoirs beneath salt bodies or along their steep flanks poses two serious problems for conventional seismic imaging technologies. First, the seismic waves reflected off the steep flanks of subsurface features travel almost horizontally, which poses a problem for standard imaging algorithms. Second, the top-of-salt structure is often highly irregular, which scatters seismic waves into multiple paths. This is because seismic waves generally have a much higher velocity when traveling through low-density salt than through surrounding sediments. Unless the imaging process is able to reconstruct this scattered energy, information from any wave that passes through the top of the salt mass is effectively lost or only partially imaged. These factors, if not taken into consideration, can yield misleading data about the location and geometry of prospective formations and seldom provide sufficient information to properly locate an exploration well.

Reverse time migration

The reverse time migration (RTM) algorithm is a simple migration technique that, until recently, was too compute-intensive to use in a commercial 3-D or wide-azimuth setting.

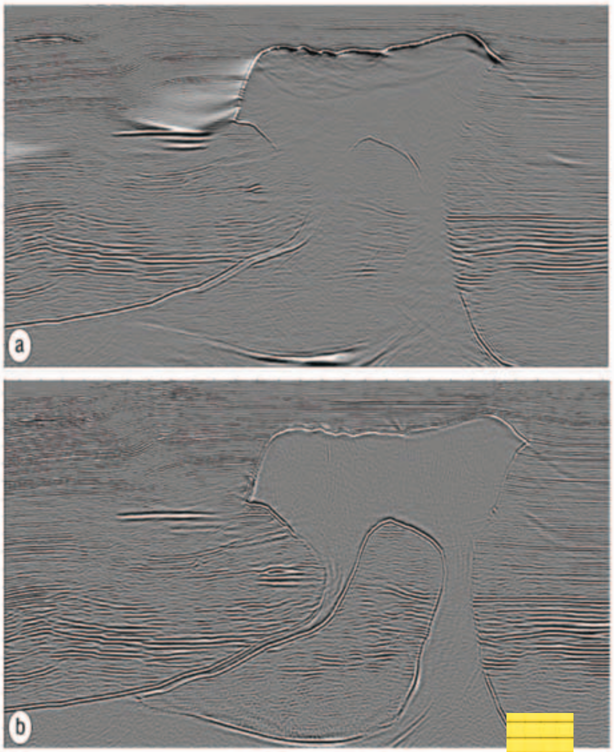

Figure 1. (a) Synthetic data migrated with a one-way wave-equation algorithm; (b) Synthetic data migrated with a two-way RTM algorithm.
Images courtesy of GXT Imaging Services

Broadly, the four migration families include RTM, one-way wave-equation migration (WEM), Kirchhoff migration, and beam migration. The ray-based or integral techniques propagate the source and the receiver wavefields down to each potential reflector in the subsurface using high-frequency ray-based approximations.

The finite difference (FD) migrations propagate the source and receiver wavefields down to each reflector using recursive techniques.

RTM predicts the incident wavefield at each reflector using the wave equation and injects the source signature into the model at the source position. This is standard forward modeling in which the wavefield is propagated forward in time – later time samples are predicted from earlier time samples. Now, just as we can run movies backwards on computers, we can also run the wave equation backwards in time; i.e., we can predict earlier times from later times. This is done to predict the reflected wavefield at each point in the subsurface. In this case, the recorded wavefield is reintroduced into the model at the receiver locations from late to early times. To predict the reflectivity at each position, the estimated incident and reflectivity wavefields are correlated at each location and for each shot and then added to the output image cube. The key feature of this technique is that once the source and receiver energy is injected into the propagation grid, there are no amplitude approximations. The wavefield is propagated as an acoustic wavefield, and there are no limitations on propagation with direction.

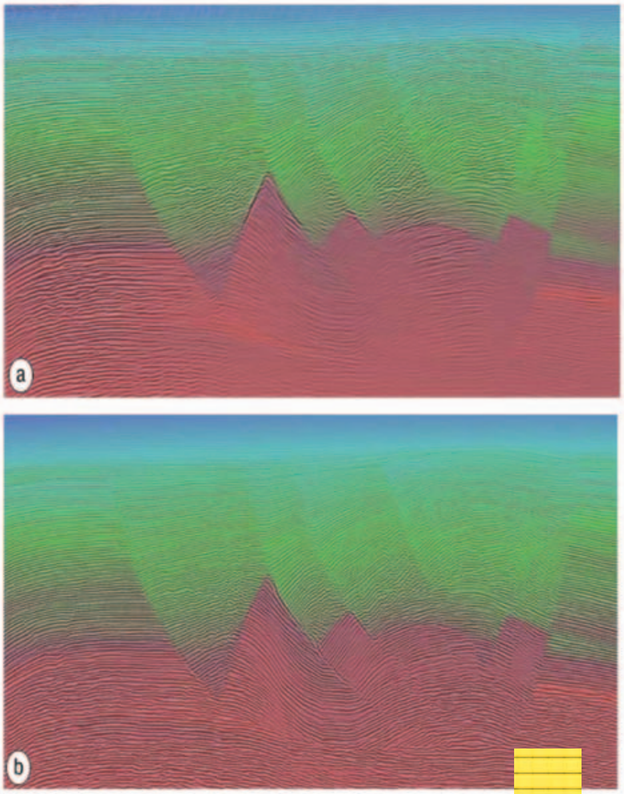

Figure 2. (a) Beam migration of TTI synthetic model; (b) RTM of TTI synthetic model. Note the well-imaged faults and deeper structure below the complex fault blocks.

Data courtesy of BP

Standard one-way wave-equation methods use a similar technique to predict the source and receiver wavefields in the subsurface, but the wavefield is propagated in depth instead of time. The source wavefield is recursively propagated into the subsurface under the assumption that this wavefield always propagates downwards, while the reflected wavefield is recursively propagated into the subsurface under the assumption that it always propagates upwards. If the wavefield propagation is closer to horizontal, an inferior estimate of that wavefield extrapolation will be computed.

To demonstrate the potential of RTM in comparison to one-way wave-equation methods, consider the complex isotropic acoustic FD synthetic data example shown in Figure 1. Figure 1a shows the result of migrating the data with a one-way WEM algorithm, while Figure 1b shows the result of migrating the data with RTM. In the one-way image, the turning-ray energy that illuminates the overhanging and steep portions of the salt stem cannot be handled and often causes it to not be imaged (due to algorithmic dip limitation) or illuminated by the acquisition. Steep dips and the turning-wave energy, as well as energy from other two-way ray paths, are handled by RTM, producing a good image. The one-way migration examples shown in this paper were obtained using a split-step Fourier plus interpolation algorithm.

Kirchhoff and beam migration-based techniques propagate the source and receiver wavefields down to each potential reflection point using ray-based techniques. These techniques are based on high-frequency solutions to the wave equation. Typically, beam techniques support multi-valued propagation of the source and receiver wavefields, whereas Kirchhoff algorithms do not. These techniques are capable of imaging steep structure, which is the weakness of WEM techniques, but are not able to image well below or near complex velocity structures, such as adjacent to or below salt bodies or faulted structures. Figures 2a and b show the weakness of beam migration on model data provided by BP. The model is a tilted transverse isotropy that is designed to represent the offshore geology that might be found near the northern portions of South America. The anisotropic axis of symmetry in the model was

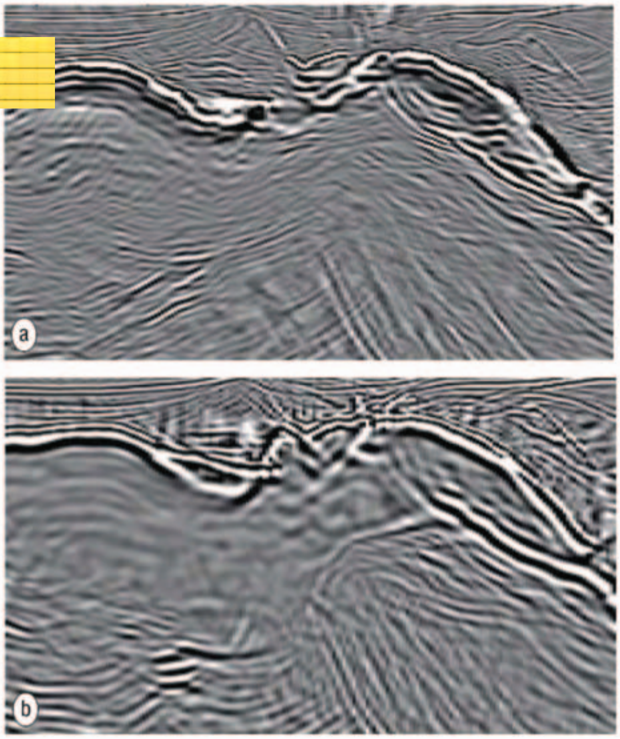

Figure 3. WEM (a) and RTM (b) images of a salt body. The base of salt and subsalt reflections are far clearer on the RTM image than on the WEM image.

perpendicular to the reflections. It is clear that the RTM image in Figure 2b is superior to the beam migration image in Figure 2a. This is evident in the areas both above and in the faults.

Barriers to RTM adoption

Given the benefits of RTM migration relative to the other migration techniques and given that the RTM algorithm has been known for many years, why hasn't it been used very much?

One reason is the relative computational cost of the algorithm. Until recently, compute demands of the algorithm were simply too great to make its use widespread. With the advent of cluster computing, this barrier was eliminated, and this in turn led to the development of new and more efficient wavefield propagation techniques. Today, large volumes of data can be efficiently processed by RTM without bandwidth limitations.

Another reason the seismic industry has been cautious about RTM is the perception that it is more sensitive to model accuracy than the other migration techniques. Simply stated, there is an opinion that unless we know the model to a high level of accuracy, which is greater than we can achieve with current technology, RTM will either produce inferior images, or we won't see the benefit of applying it. Our experience, based on the large volume of RTM migrations that we have run, has shown that this perception is ill-founded. Figure 3 captures our experience to date with this technique. What we see is, in an imaging project where we don't know the model very well, RTM does not yield significantly better images than other methods. But even with that poor model, RTM will image steep dips. However, as our knowledge of the model increases, the RTM images become noticeably better than the images produced with the other techniques. Furthermore, based on our experience, we have never seen a case in which the RTM images are inferior to the images produced using the other algorithms independent of the accuracy with which the model is known. What we have found is that the key to capitalizing on the benefits of RTM is to build better models by using RTM in the model-building phase of a project. This has led to the generation of better models in a reduced amount of time.

Conclusions

In order to produce better exploration results such as prospect leads and accurate drilling decisions, we need to build reliable images in a timely fashion. To reach these results, we need better models faster. Because of RTM's superior dip-handling characteristics, the ideal way to build these models involves the use of RTM. Using RTM throughout the imaging cycle will lead to reduced exploration risks and a potential shortening of the exploration cycle.

RTM also is more suitable for imaging anisotropic structures than either ray or one-way migration schemes. This will become increasingly more important in the context of wide-azimuth acquisition. ■

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