Chapter 5

Exploding Reflector Examples

Let's turn our attention to a few simple zero-offset examples. In this case, we only want to compare algorithms. True zero offset data should provide a complete and accurate image of the subsurface. Since the data we will image is synthetic, we will have an exact representation of the true result.

Using our exploding reflector modeling approach, we generate what might be called true zero-offset seismic sections. These sections are then migrated using some new and some very old methods. Visual comparisons provide conclusive evidence that using the most accurate algorithm usually produces the best possible image.

If we are correct in our theoretical analysis, reverse time migration should produce almost exactly the correct answer in the following examples. Since reverse-time migration does not have any information about amplitudes in the subsurface at the start of the migration, we should not expect a perfect result. Nevertheless, the final reverse-time image should be the best, so we will use it as the baseline throughout the following examples.

Canadian Glauconitic Channel Play

Figure 5-1 shows a hard rock channel play velocity model together with a zero-offset exploding reflector simulation. Two channels are visible just below 700 meters. This model is based on glauconitic channel plays in Canada. The job is to image the channels just below 1300 milliseconds.

Figure 5-1. A shallow hard-rock-channel play from Alberta Province in Canada.

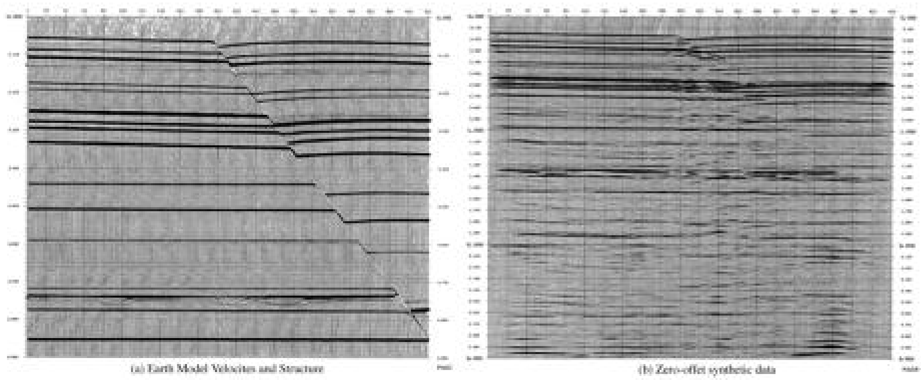
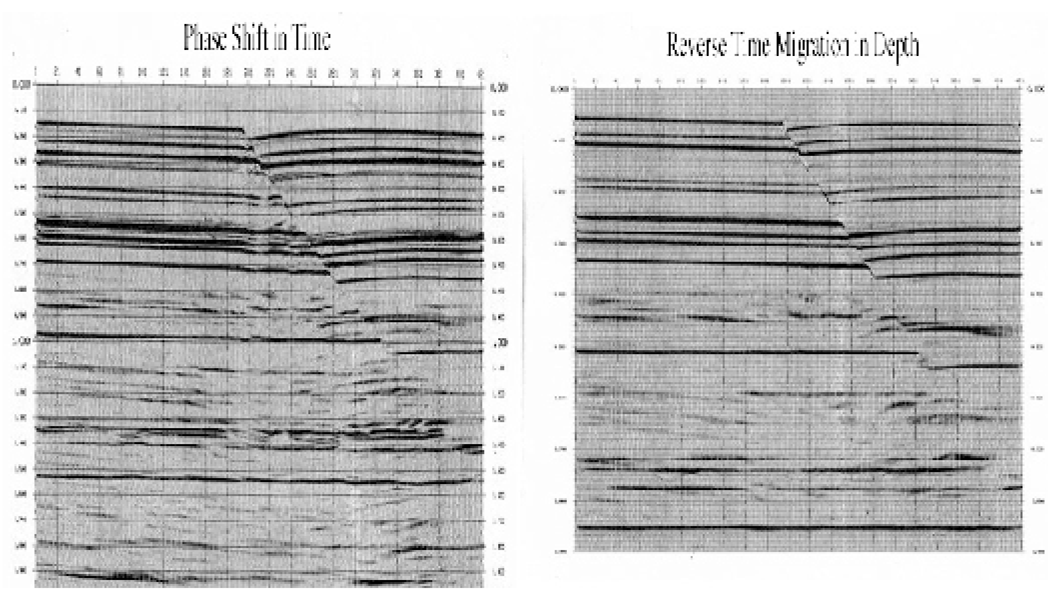


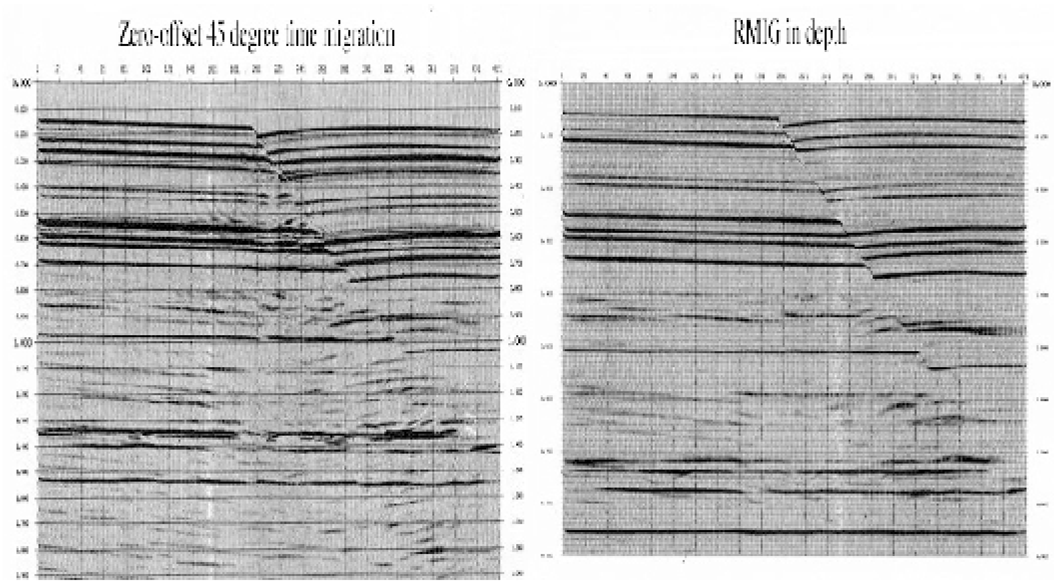
Figure 5-2 shows a pure phase-shift migration versus a two-way reverse time migration. Note that while the phase-shift was performed as a time migration, and the reverse time migration was actually a depth migration, a simple squeeze plot of the depth migration provides an excellent basis for direct comparison between the two images.

Figure 5-2. Phase shift versus full two-way-reverse-time migration.



In Figure 5-3, the 45 degree migration was produced by an approximation to the one-way wave equation that was expected to image dips only up to approximately 45 degrees. Such migrations were the rule for many years and were considered to be the best possible migrations by many contractors. Clearly, the reverse-time migration on the right is superior to the 45 degree migration on the left. In this case, the improved accuracy of the reverse time method is preferable.

Figure 5-3. 45 degree time migration versus full two-way-reverse-time migration.



The FK or Stolt migration on the left of Figure 5-4 works well for this example. Velocity variations are not strong, so the constant velocity assumptions inherent in this approach are not a serious issue. Still, the reverse-time migration on the right is probably better.

Figure 5-4. FK versus full two-way-reverse-time migration.

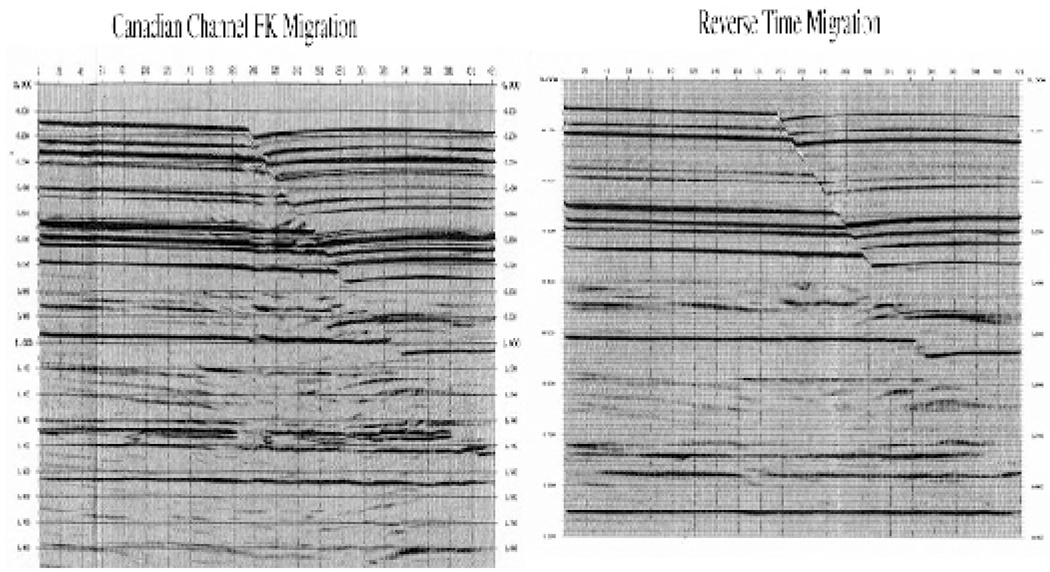
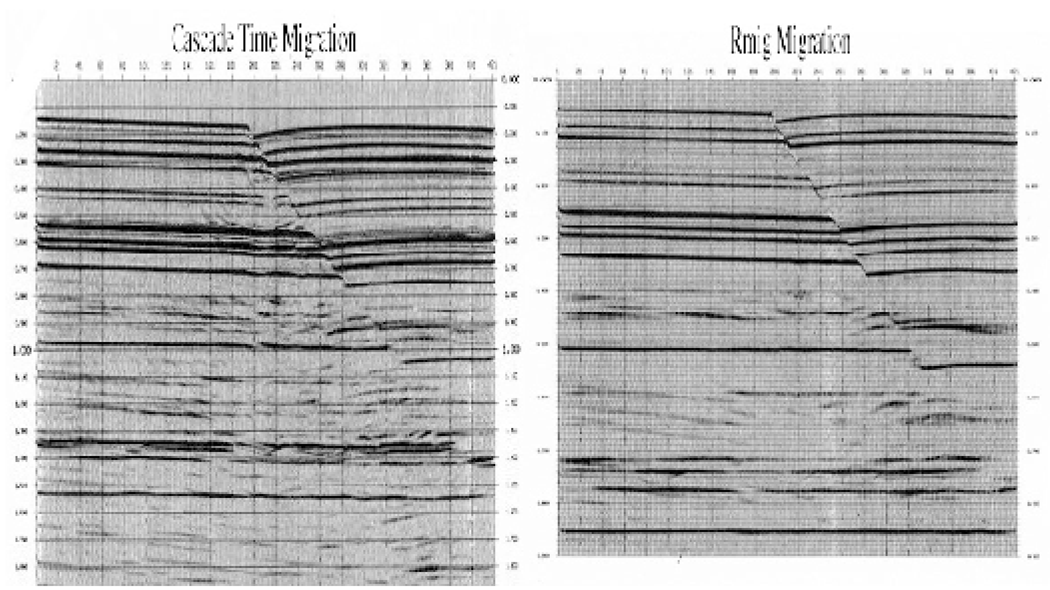


Figure 5-5 shows that cascading migrations produce the best comparison between migration techniques. However, the reverse-time migration still has fewer artifacts and appears much clearer.

Figure 5-5. Cascade versus full two-way-reverse-time migration.

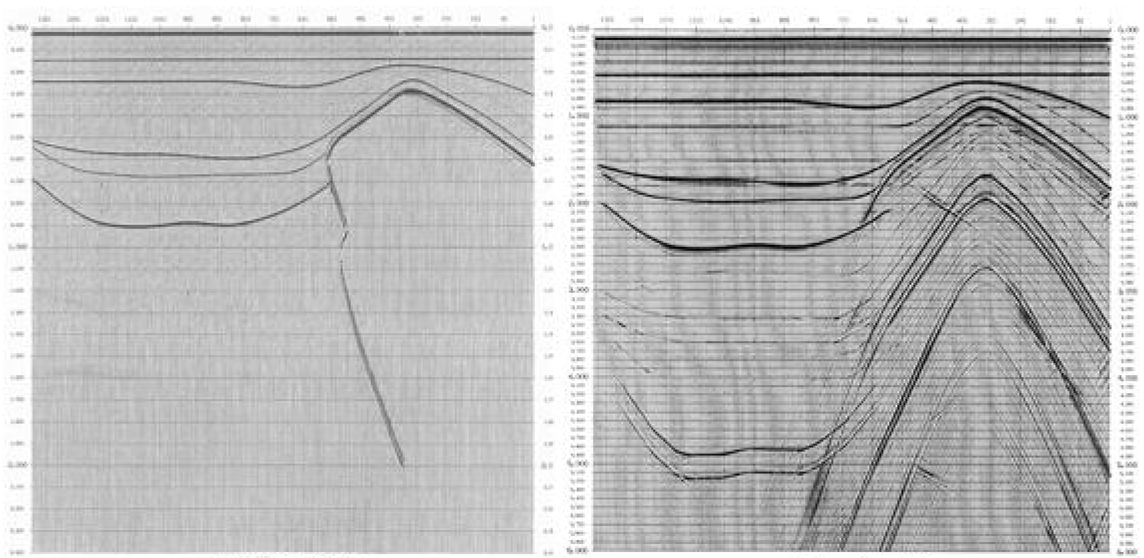


Gulf of Mexico Salt Model

Figure 5-6 shows a typical Gulf of Mexico salt structure with associated zero-offset exploding reflector synthetic data. The play here is in the beds that terminate at the salt-sediment interface. The geology is such that, except for the salt-sediment interface, velocity variation is relatively small.

However, from an imaging point of view, the extreme 2:1 or even in some cases 3:1, velocity contrast between the sediment and the salt represents a very difficult problem for most imaging algorithms to handle. The challenge is to image the salt face and the corresponding sediment terminations. The Gulf of Mexico salt structure has some of the steepest dips of all the models considered in this section. We should expect reverse time migration to win this contest easily.

Figure 5-6. A Gulf of Mexico Salt Earth Model and Exploding Reflector Data.



(a) Earth Model in Depth (b) Zero offset synthetic

Figure 5-7 compares phase shift migration versus two-way reverse time migration. As we will see, regardless of which migration algorithm we use, the reverse time approach does the best job of placing all the events at their proper location. Unlike its time-domain based counterparts, it places all events as close as possible to where the velocity model says they should be.

Figure 5-7. Phase shift versus full two-way-reverse-time migration.

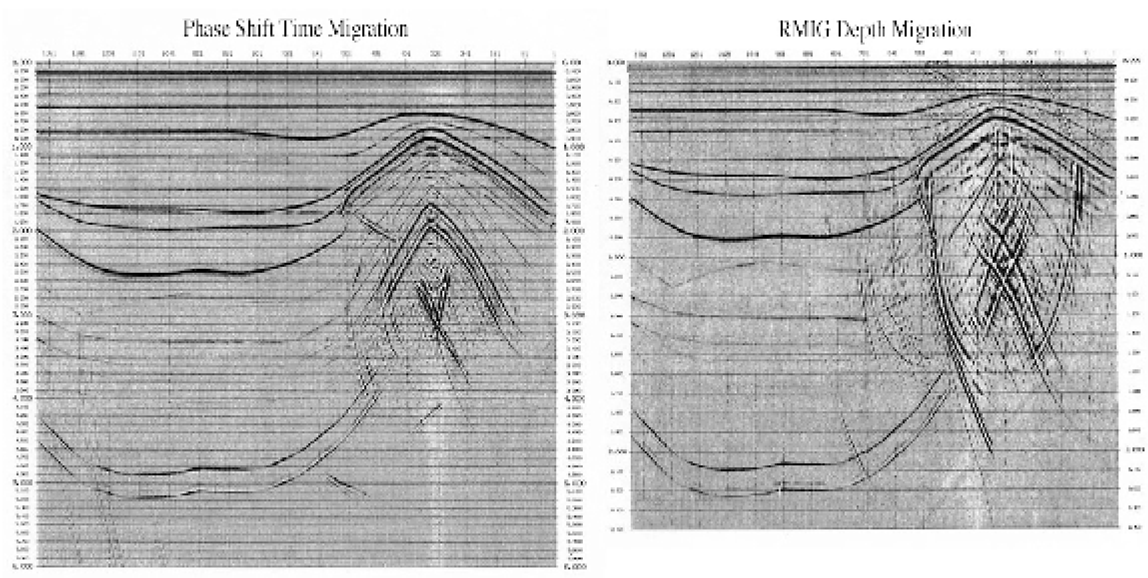


Figure 5-8 compares 45 degree migration versus two-way reverse time migration. From a purely esthetic point of view, we could argue that the 45 degree migration on the left is superior to the reverse-time migration on the left. One reason for this is the inherent dip-filtering that the 45 degree limit produces. Dips beyond 45 degrees are essentially lost, so the salt face will never be properly imaged, but because they are lost, the image looks much cleaner.

Figure 5-8. 45 degree versus full two-wayreverse-time migration.

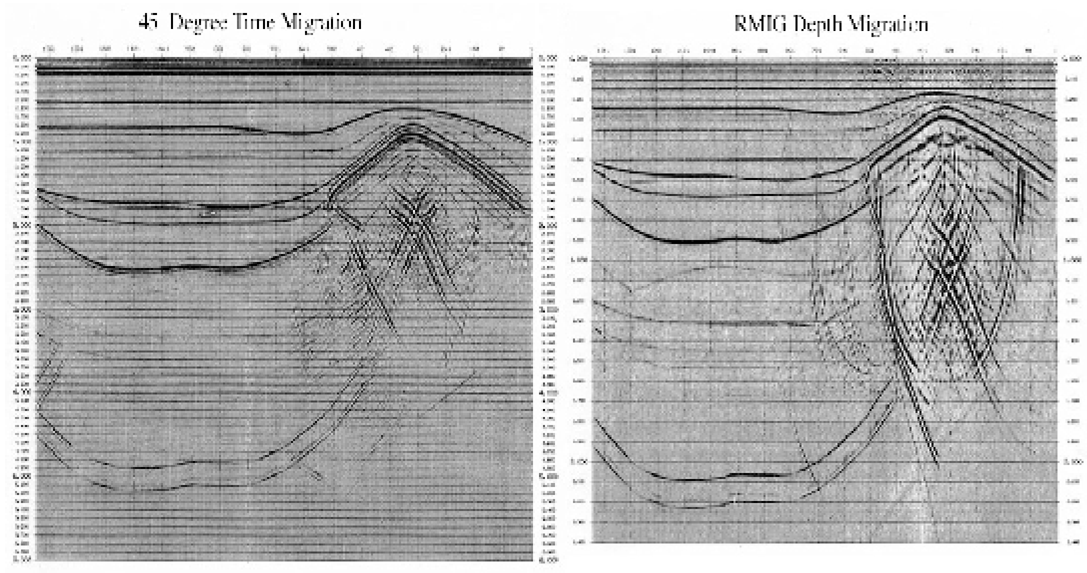
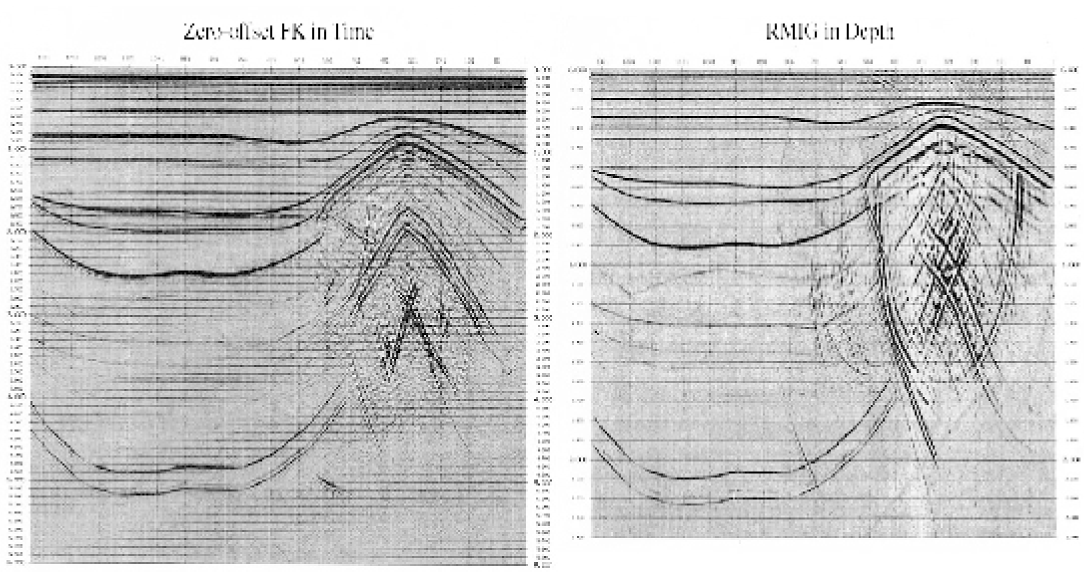


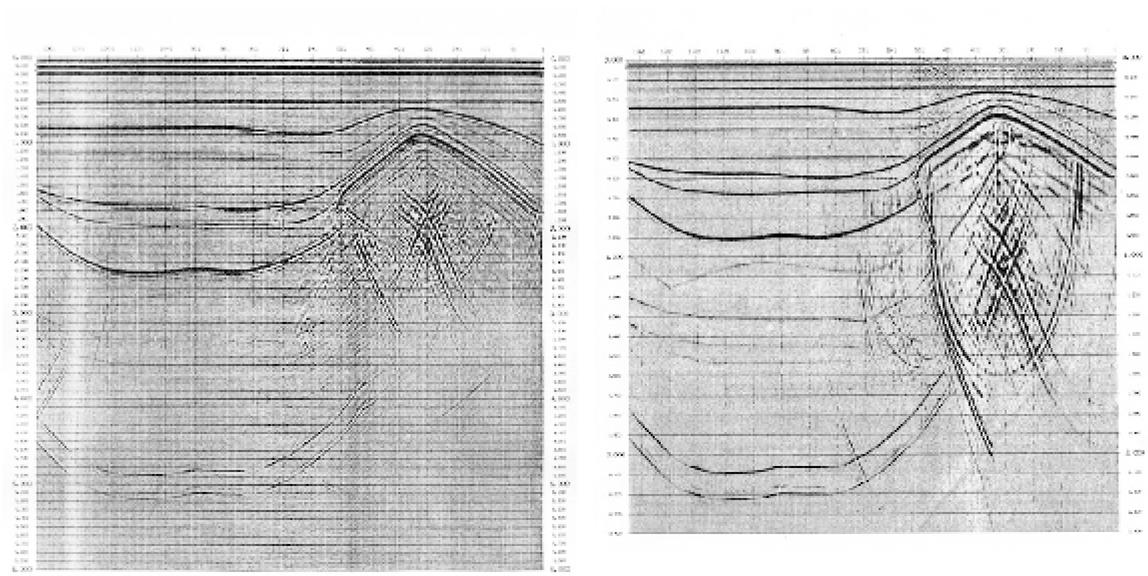
Figure 5-9 compares FK migration versus two-way reverse time migration. Because it is so sensitive to the constant velocity assumption used to derive it, an FK migration has no chance of imaging the salt face at its proper position. What is more surprising is that the salt face is almost not imaged at all.

Figure 5-9. FK versus full two-way reverse-time migration.



The cascade migration in Figure 5-10 does a very nice job on this zero-offset data set. We can argue that it is in fact the best of all the time-migration results. Nevertheless, the image is not nearly as good as the two-way graphic on the right.

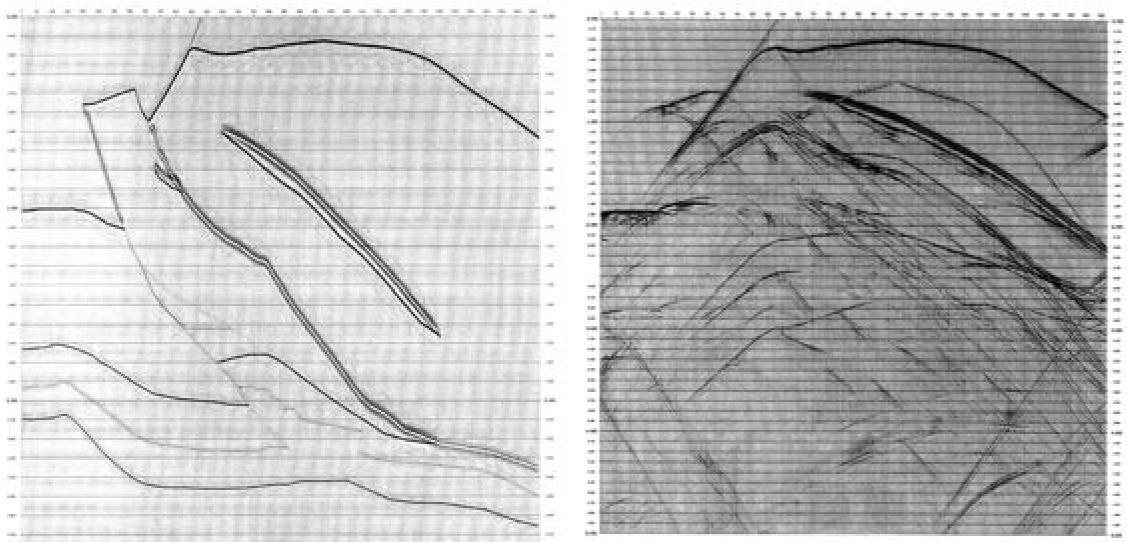
Figure 5-10. Cascade versus full two-way-reverse-time migration.



Granitic Overthrust

Figure 5-11 shows a granitic overthrust model from the Northern United States together with a simulation of a zero-offset section using that model. The problem is to unravel this data and put it back in its proper location. The objective are the sediments below the granite thrust.

Figure 5-11. A Granitic overthrust example from the state of Wyoming in the United States of America.



(a) Granitic overthrust Earth Model velocities (b) Zero-offset synthetic time data

Granitic overthrusts are certainly as difficult to image as salt structures. Granitic structures are representative of structures with velocity contrasts between 3 and 3.6 to 1, where granite velocities are usually between 6800 and 7000 m/s, while near surface velocities are in the neighborhood of 1800 m/s.

Imaging the top and base of such structures with a time migration is almost impossible.

Figure 5-12 shows that a comparison of phase shift migration with reverse time migration is in reality no comparison at all. A single velocity function simply cannot cope with the extreme variation in the actual Earth model.

Figure 5-12. Phase shift versus full two-way-reverse-time migration.

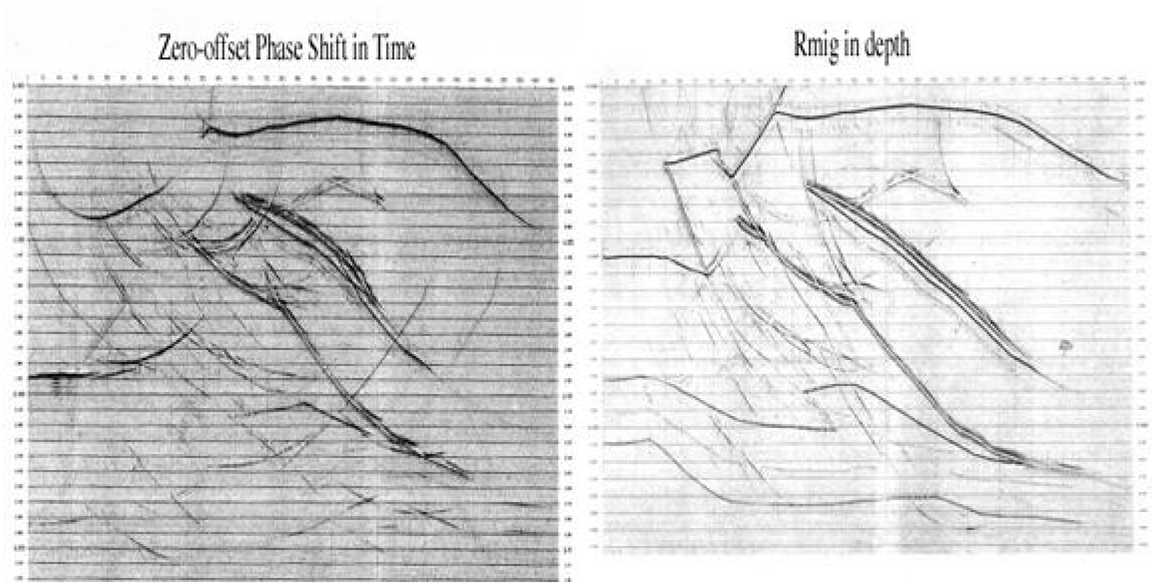
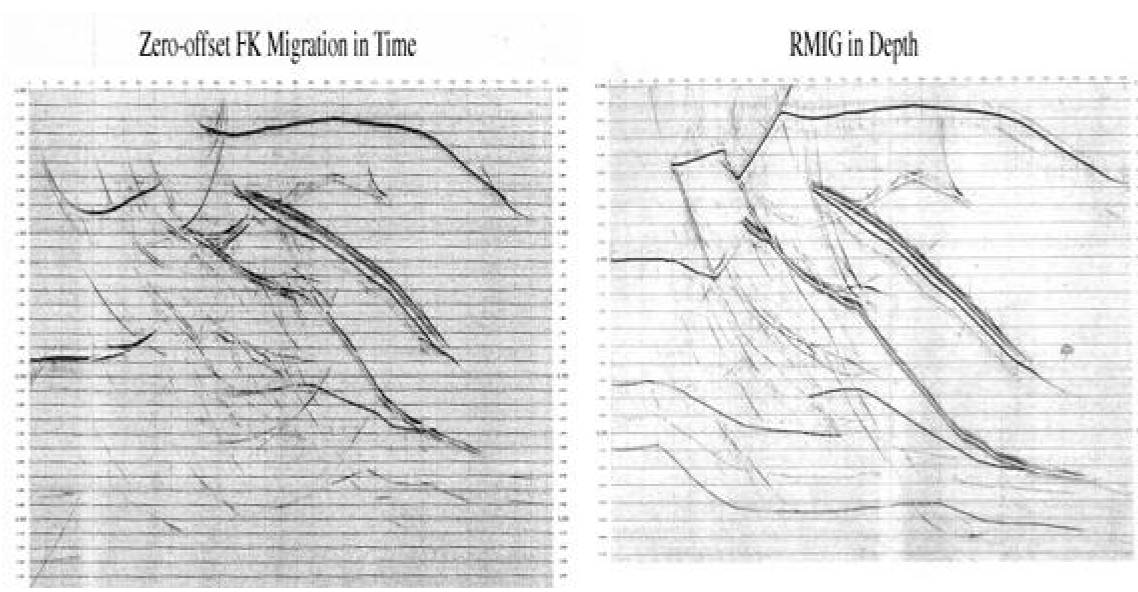


Figure 5-13 shows that an FK migration is no better than the phase shift of the previous figure.

Figure 5-13. FK versus full two-way-reverse-time migration.



In contrast to the previous methods, the cascade migration shown in Figure 5-14 does a superior job of imaging above and to the left of the granitic intrusion, but simply cannot image anything below the granitic overthrust accurately.

Figure 5-14. Cascade versus full two-way-reverse-time migration.