3-D reverse-time migration using acoustic wave equation: An experience of SEG/EAGE salt data set

Kwangjin Yoon*·Changsoo Shin ·Soonduk Hong [1)]

Seungjin Yang [2)]·Sangyong Suh [3)]

Abstract

Reverse-time migration has no dip limitations and one of the most promising methods to preserve true amplitudes. We applied 3-D prestack reverse time migration based on a pseudo-spectral implementation of the acoustic wave equation to the **SEG/EAGE** salt dome synthetic data set. We were able to illuminate sub salt reflectors of the **SEG/EAGE** salt model that were barely observable in the Kirchhoff migration images. Using the pseudo-spectral modeling technique, we could implement reverse-time migration within the core memory, which could be equipped to a personal computer.

Introduction

Because of its speed, ability to image very steep dips, and the need to update the velocity model in an iterative manner, Kirchhoff migration is still the most commonly used 3-D prestack migration algorithm. However Kirchhoff migration faces difficulties in complex geological structures where multipathing occurs and beneath rugose horizons such as faulted salt domes where traveltime calculations become difficult.. Compared with Kirchhoff migration, wave equation migration is in general more accurate but is significantly more computationally intensive. With the growth of massively parallel processors (or MPP) machines, geophysicists can go beyond Kirchhoff migration, and begin to consider wave equation migration algorithms including paraxial, phase shift plus interpolate, phase screen, pseudo screen, and other one-way wave equation solutions of the wave equation for more routine use.

Reverse time and least-squares (derived from inversed theory) migration algorithms are more computationally intensive still, but provide illumination of steep dips including overturned features, while promising to better preserve true amplitudes. 2-D reverse-time migration was introduced soon after the first finite difference modeling algorithms were developed about 25 years ago (Hemon, 1978; Baysal et al., 1983; Loewenthal and Mufti, 1983; McMechan, 1983). With the growth of computer power, , geophysicists have applied reverse-time migration to 3-D imaging (Chang and McMechan, 1994; Wu et al., 1996). Reverse-time migration is expensive and, especially in 3-D, may be difficult to implement even when using large shared memory computers. The use of higher-order accuracy FD algorithms (Wu et al., 1996) and excitation time approach (Chang and McMechan, 1994) help to reduce CPU time and memory. We follow Gazdag(1981) and Kosloff and Baysal(1982) and use the pseudo-spectral method to further reduce CPU time and core memory requirements. For smooth earth models appropriate for migration where we wish to minimize backscattering events while accurately modeling propagation effects, the earth can be, discretized with only 2 grid points per wavelength. In order to save disk space, Green's functions were stored at the Nyquist sampling interval $1/f_{max}$, where f_{max} is the maximum frequency of the source wavelet. We will compare reverse-time migration images with first arrival traveltime Kirchhoff migration images. By showing that 3-D reverse-time migration gives well-defined sub salt images of the SEG/EAGE salt dome model, we hope to demonstrate that 3-D reverse-time migration could produce high fidelity images under the PC-based distributed memory cluster machine.

1) Seoul National University

2) Hanyang University

3) KIGAM

Application to the SEG/EAGE salt dome model data set

In this numerical experiment, we migrated the **SEG/EAGE** narrow azimuth data set using 3-D reverse-time migration and 3-D Kirchhoff migration using first arrival traveltimes. In Figures 1 and 2 we show migrated images at inline 490, or x=9.78km. In Figures 3 and 4 we show migrated images at crossline 360, or y=7.18km. Figure 1 and Figure 3 are obtained by 3-D reverse-time migration, while Figures 2 and 4 are produced using the 3-D first arrival Kirchhoff migration. As shown in both the inline and crossline images, both Kirchhoff and reverse-time methods are effective in accurately imaging reflectors above the salt body. However, in the subsalt area, Kirchhoff migration images are contaminated with noise and artifacts. In the reverse-time migration images, we can identify reflectors in their correct locations, even though their amplitudes are weak. Figure 5 and Figure 6 are depth slices of reverse-time and Kirchhoff migration images at the depth of 2.98km crossing the subsalt area horizontally. In the depth slice generated by reverse-time migration shown in Figure 5, we see weak reflectors and a clear salt boundary. However, the depth slice generated by Kirchhoff migration, the salt boundary and other reflectors are not shown clearly.

Computational resources

In this reverse-time migration, we used the image aperture covering 3.2km, 4.2km and 4.2km in crossline, inline and depth directions, which corresponds to 160, 210 and 210 grid points of the SEG/EAGE salt dome model. Reverse-time migration of a shot-gathered data took an average of 7 hours of CPU time using an IBM nighthawk Power3-II 375MHz CPU requiring 400 MB of memory and 10GB of disk space. For the 4800 shots, reverse-time migration took one month using 48 CPUs. For the Kirchhoff migration, we used a cluster machine composed of 32 Pentium-IV CPUs. Kirchhoff migration required about 2 days using 26 CPUs and a dynamic image aperture whose radius varied from zero to 1.5km. Our implementation of reverse-time migration was therefore about 15 times as expensive as our Kirchhoff algorithm. However, because current PCs have enough memory to execute this reverse-time migration, it is expected that we could implement 3D reverse-time migration using economical PC-based cluster machines in a near future.

Conclusions

Many workers have attempted to image beneath the **SEG/EAGE** salt dome but the results are often disappointing. To our knowledge, the results we have obtained by a brute 3-D reverse-time migration based on acoustic wave equation has provided some of the most accurate results to date.

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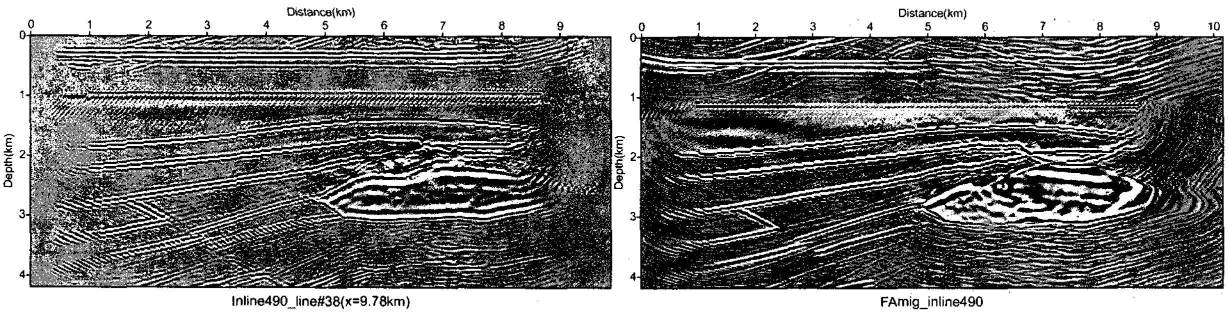
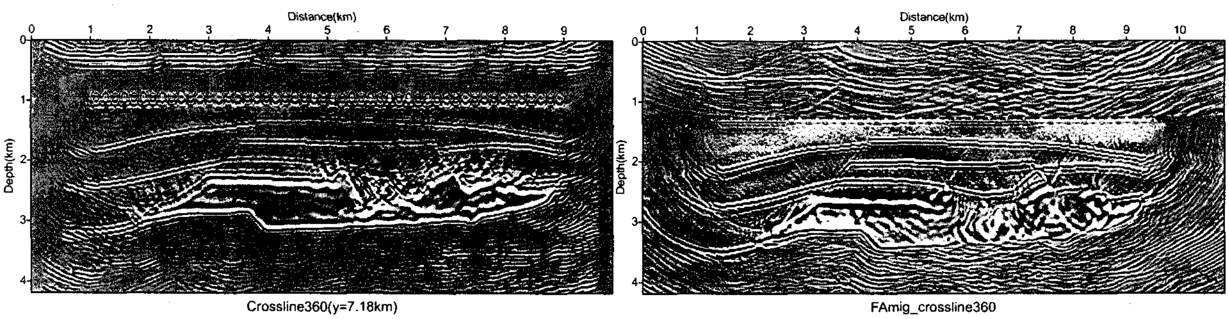


(a) (b)

Figure 1. 3-D a) reverse-time migration image and b) first arrival Kirchhoff migration image of SEG/EAGE salt data at inline490, x=9.78km.



(a) (b)

Figure 3. 3-D (a) reverse-time migration image and (b) first arrival Kirchhoff migration image of SEG/EAGE salt data at crossline360, y=7.18km.

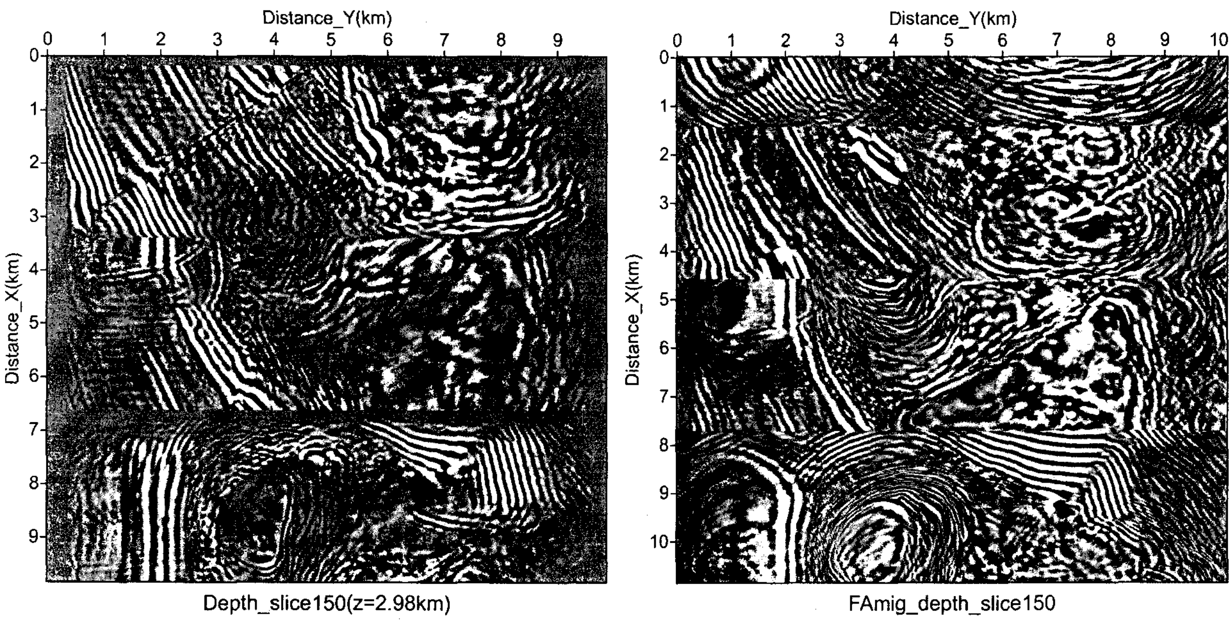


Figure 5. 3-D (a) reverse-time migration image and (b) first arrival Kirchhoff migration image of SEG/EAGE salt data at depth-slice150, z=2.98km.