Multicomponent depth migration for a modified 2D elastic SEG/EAGE salt model

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Summary

Multicomponent elastic wave prestack depth migration is tested using a synthetic data set. The migration method is based on the elastic screen propagator, equipped with a wide-angle correction and a vector imaging condition. The synthetic data set is generated using a full-wave elastic finite-difference method. A two-dimensional elastic model modified from the acoustic SEG/EAGE salt model is used in the finite-difference calculation and the following migration. The synthetic data is separated into pure *P*- and *S*-waves before conduct the migration. Both *P-P* image and *P-S* converted wave image are obtained from the migration. By adopting the vector imaging condition, correct polarization can be obtained for *P-S* wave image. Partial images from different sources with correct polarizations are stacked for generating the final image.

Introduction

The multicomponent elastic data significantly increased the information about the subsurface structure. From these data, more petrophysical parameters may be obtained. However, extracting the new information requires more sophisticated imaging/inversion techniques. Several types of methods, e.g., elastic reverse-time migration (Chang and McMechan, 1994), elastic wave Kirchhoff migration (Hokstad, 2000), migration using displacement potentials (Zhe and Greenhalgh, 1997), have been proposed to carry out elastic wave migration. Based on the successful applications of scalar wave phase screen (split-step Fourier) migration and its improvements (Stoffa et al., 1990; Ristow and Ruhl, 1994; Jin, et al., 1998; Xie and Wu, 1998; Huang and Fehler, 2000; Xie et al., 2000), as well as the development of elastic wave screen propagator in seismic wave modeling (Wu, 1994, 1996; Wild and Hudson, 1998; and Xie and Wu, 2001a), Xie and Wu (2001b) developed a multicomponent migration method based on the elastic screen propagator. Like in the scalar wave case, the elastic screen propagator is a one-way wave equation based method. It retains the advantages of the original screen method and provides an efficient and accurate approach for multicomponent elastic wave migration. Equipped with a wide-angle correction, the new method can be used under large velocity contrast and wide scattering angles. Their vector image condition gives correct polarizations for converted wave image, which makes the stacking of partial images a straightforward procedure.

In this paper, we will test the new multicomponent elastic migration method using a 2D elastic model. The elastic model is a modified version of the acoustic SEG/EAGE salt model. Based on this model, the synthetic data set is generated using a finite-difference method. Using the new multicomponent elastic migration method, both *P-P* image and *P-S* converted wave image are obtained and compared with the original model.

Two-Dimensional Elastic SEG/EAGE Salt Model and Synthetic Data Set

Our two-dimensional elastic SEG/EAGE salt model is modified from the 2D profile A-A' of the SEG/EAGE salt model (O'Brien and Gray, 1996; Aminzadeh, et al., 1997). The original salt model is an acoustic model with only sound speed. To make this model meets the requirements of elastic modeling/migration, several modifications have been made. We use the sound speed as the *P*-wave speed. The *S*-wave speed is obtained from the *P*-wave speed by assuming $V_P = 1.73 V_S$. The density is determined based on Birch's Law (Fowler, 1990). Since the elastic finite-difference code cannot handle a water layer, we eliminated the top water layer by filling it with a layer of material similar to the sub-water layer. The interface between the water layer and the solid sea bottom has also disappeared. Shown in Figure 1 is the *P*-wave velocity of the modified salt model.
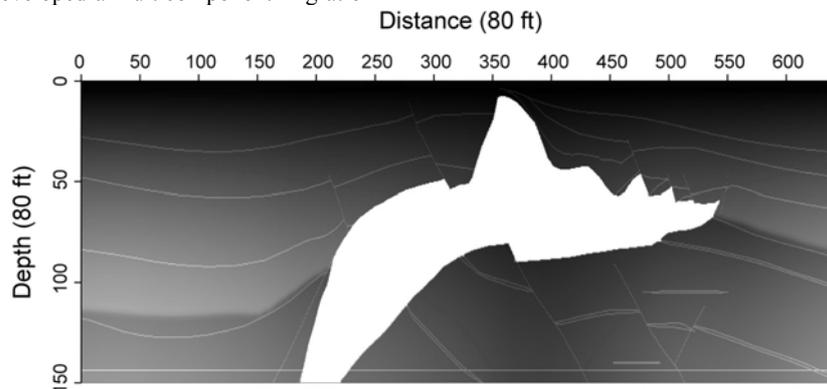

Fig. 1. A modified version of the A-A' from the SEG/EAGE salt model. Details see the text.

The synthetic data is generated using a full-wave fourth-order elastic finite-difference method. A velocity grid with $dx = dz = 20$ ft, and $dt = 1$ ms is used for finite-difference calculations. One hundred and twenty shots are used to illuminate the model. Each shot has 160 receivers. The P- and S-waves are separated by calculating the divergence and curl of the displacement field (Sun, et al. 2001). Shown in Figure 2 is a typical shot gather section. The shot is located at a horizontal distance x = 5760 ft (trace number 72 in Figure 1). The left panel is for mixed P- and S-waves. The horizontal component is mainly composed of P-waves, and the vertical component is dominated by S-waves. The middle and right panels are separated pure P- and S-waves. Due to the separation process, there are some waveform distortions in the separated waves. The subsurface structure under the shot is relatively simple. Several reflections from underlying interfaces can be clearly identified. The wide-angle later arrivals are reflections from the left flank of the salt body. Shown in Figure 3 is another section for a shot located at x = 25760 ft (trace number 322 in Figure 1). Compared to Figure 2, seismograms in this section show many complexities due to the complicated subsurface structures.
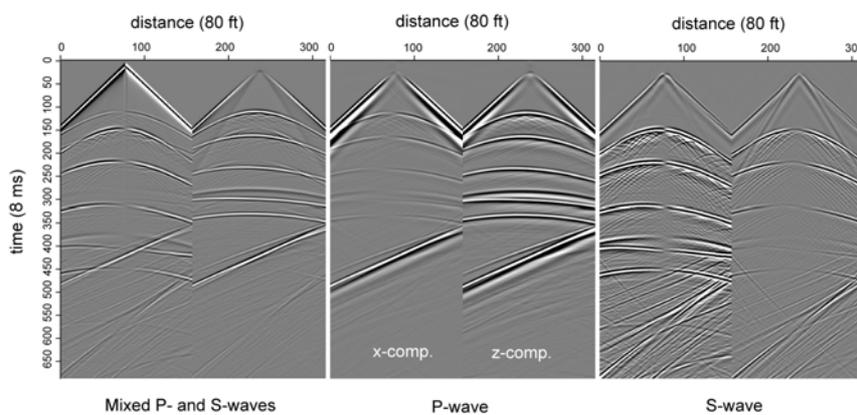

Fig. 2. A synthetic shot gather section. The shot is located at horizontal distance x = 5760 ft. In the left panel is mixed P- and S-waves. In the right two panels are separated pure P- and S-wave sections. Within each panel, on the left is the horizontal component and on the right is the vertical component. First arrivals are eliminated from separated P- and S-waves.

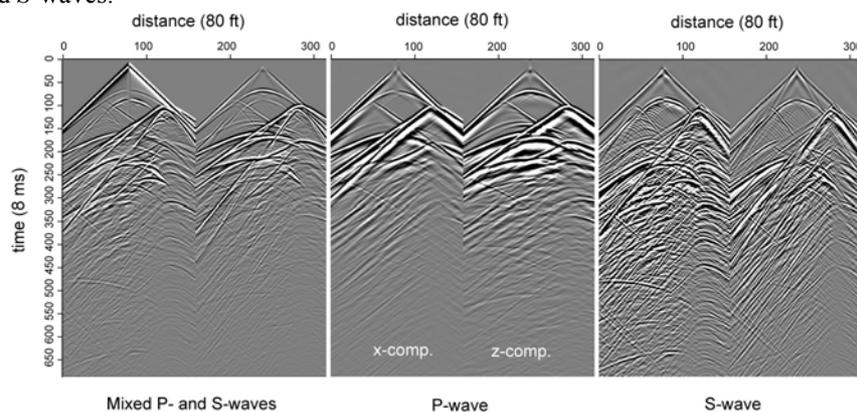

Fig. 3. A synthetic shot gather section similar to Figure 2, except the shot is located at horizontal distance x = 25760 ft. Compared to Figure 2, there are many complicated features in this synthetic section.

Migration/imaging

The migration is performed using the multicomponent elastic screen propagator together with the wide-angle correction (Xie and Wu, 2001b). The downgoing wave is propagated from the source to the target, and the upgoing P- and S-waves are backpropagated from the receivers to the target. A vector imaging condition (Xie and Wu, 2001b) is used to generate images. Partial images from

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individual shots are stacked to generate final images. The migrated *P-P* image and *P-S* converted wave image are shown in Figure 4. Generally speaking, the *P-P* image is better than the *P-S* image, resulting from the fact that a reflected *P*-wave usually has the better signal to noise ratio. In the *P-P* image, both the salt body and interfaces are well imaged. Some sub salt reflectors are also shown. Weak coherent noises can be seen both inside and below the salt body. Careful analysis shows that these noises are mainly from locally converted waves in the up- and downgoing legs. Comparing to the *P-P* image, the *P-S* image is weaker and noisier. Part of the reason is that in the deeper part of the model, the incident angle for the incoming *P*-wave is rather small (near vertical incidence) and the *P* to *S* reflection is weak. However, major subsurface structures are still properly imaged. For both *P-P* and *P-S* images, baselines at the bottom of the model are rather flat. This means, even with the existence of a very high velocity contrast, the wide-angle elastic propagator correctly extrapolates *P*- and *S*-waves to the bottom of the model. *P*- and *S*-wave images carry different information on the subsurface structures. Combining these images together will give us more information on the elastic properties of the reflectors.
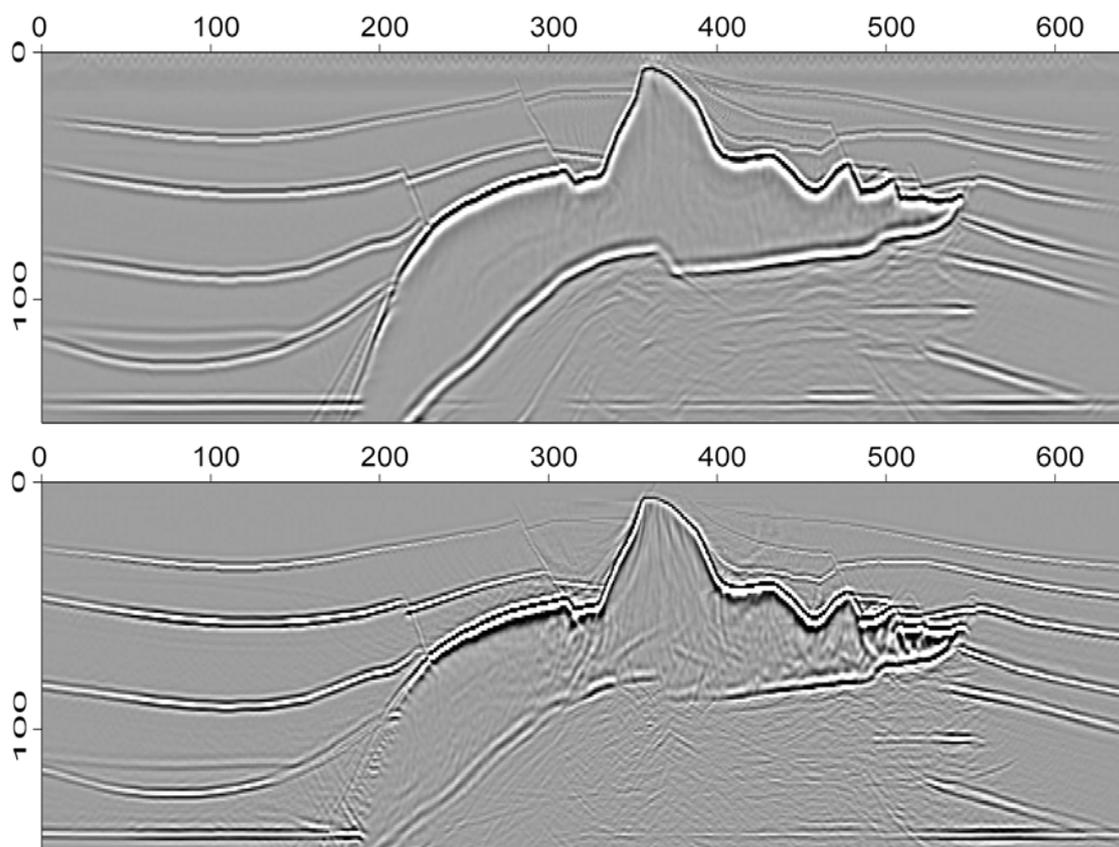

Fig. 4. Migrated images of the elastic SEG/EAGE salt model. Upper panel: *P-P* image; lower panel: *P-S* converted wave image.

Conclusion

The multicomponent migration method based on the elastic screen propagator is tested on a 2D elastic SEG/EAGE model. Both *P-P* image and *P-S* converted wave image can be obtained from the elastic migration. The wide-angle correction improves the accuracy of the propagator under large velocity contrast. The vector image condition provides correct polarizations for the converted wave image. The results show that the method provides an efficient and accurate method for multicomponent elastic prestack depth migration.

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