Viscoacoustic reverse time migration in tilted TI media with attenuation compensation

Ali Fathalian*, Daniel O. Trad and Kristopher A. Innanen
ali.fathalian@ucalgary.ca

Abstract

We present a new approach of the viscoacoustic wave equation in the time domain to explicitly separate amplitude attenuation with phase dispersion and develop a theory of viscoacoustic reverse time migration (Q-RTM) in tilted TI media. Because of this separation, we would be able to compensate the amplitude loss effect, the phase dispersion effect, or both effects. In the Q-RTM implementation, the attenuation-compensated operator was constructed by reversing the sign of amplitude attenuation. We validate and examine the response of this approach by using it within a reverse time migration scheme adjusted to compensate for attenuation. The amplitude loss in the wavefield at the source and receivers due to attenuation can be recovered by applying compensation operators on the measured receiver wavefield. After correcting for the effects of anisotropy and viscosity, numerical test on synthetic data illustrates the higher resolution images with improved amplitude and the correct locations of reflectors, particularly beneath high-attenuation layers.

Viscoacoustic wave equation in TTI media

In 2D case, we first apply the Fourier transform to the first-order linear differential equations in the time domain to obtain the frequency domain viscoacoustic wave equation and remove the memory variable equations. Next, these equations are transformed back to the time domain to derive the viscoacoustic TTI wave equation that maintains the relative constant-Q attenuation and dispersion behaviours during wave propagation. To apply these equations on RTM, we write the viscoacoustic wave equation in TTI media for the forward and backward extrapolation as:

$$\partial_t\sigma_H = \rho V^2\Big[(1+2\varepsilon)\Big[\big(a_1(2/A) + ia_2(2/AQ)\big)\Big[\big(cos\theta cos\varphi\partial_x - sin\theta\partial_z\big)u_x\Big]\Big] + \sqrt{1+2\delta}\big[(cos\varphi cos\theta\partial_x + cos\theta\partial_z)u_z\big],$$

$$\partial_t\sigma_V = \rho V^2\Big[\sqrt{1+2\delta}\big[(cos\theta cos\varphi\partial_x - sin\theta\partial_z)u_x\big] + \big(a_1(2/A) + ia_2(2/AQ)\big)\big[(cos\varphi sin\theta\partial_x + cos\theta\partial_z)u_z\big]\Big],$$

Where $A = (\sqrt{1+1/Q^2} - 1/Q)^2$. 2/A and 2/AQ are dispersion-dominated and amplitude-attenuation-dominated operators, respectively is the opening angle. The coefficients a1 and a2 are constants equal to 1. The sign of these coefficients is important for the forward and backward extrapolation

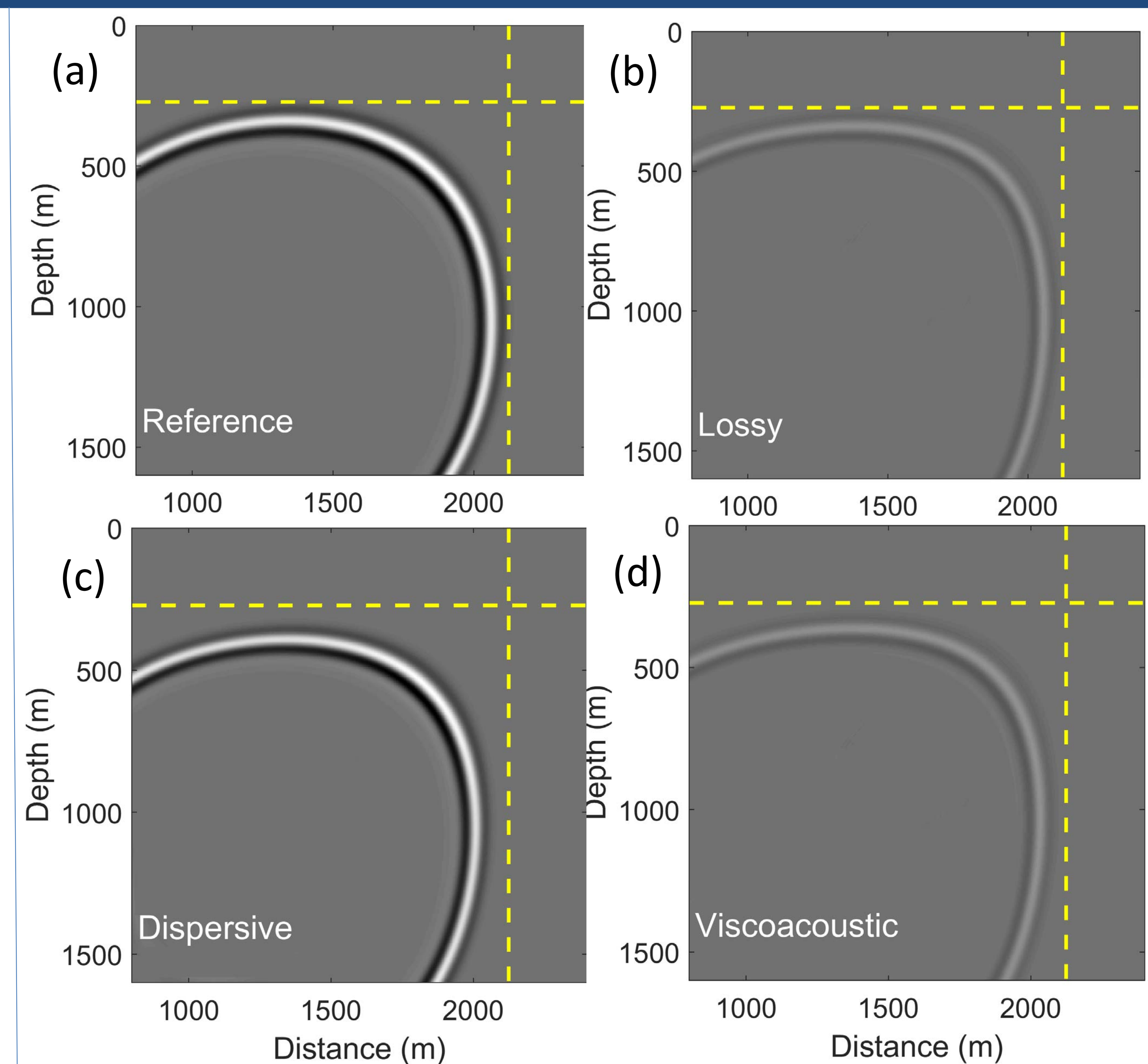

FIG. 1: 2D wavefield snapshots using (a) acoustic, (b) amplitude loss, (c) dispersive, and (d) viscoacoustic in a TTI medium with $\varepsilon = 0.2, \delta = 0.05$, and $\theta = 45^\circ$.

Viscoacoustic reverse time propagation

For the backward modelling, the viscoacoustic TTI wave equations with compensation of attenuation effects ($a_1 =$ 1 and $a_2 = -1$) can be written as

$$\partial_t\sigma_H = \rho V^2\Big[(1+2\varepsilon)\Big[\big(a_1(2/A) - ia_2(2/AQ)\big)\Big[\big(cos\theta cos\varphi\partial_x - sin\theta\partial_z\big)u_x\Big]\Big] + \sqrt{1+2\delta}\big[(cos\varphi cos\theta\partial_x + cos\theta\partial_z)u_z\big],$$

$$\partial_t\sigma_V = \rho V^2\Big[\sqrt{1+2\delta}\big[(cos\theta cos\varphi\partial_x - sin\theta\partial_z)u_x\big] + \Big(a_1\Big(\frac{2}{A}\Big) - ia_2(2/AQ)\Big)\big[(cos\varphi sin\theta\partial_x + cos\theta\partial_z)u_z\big]\Big],$$

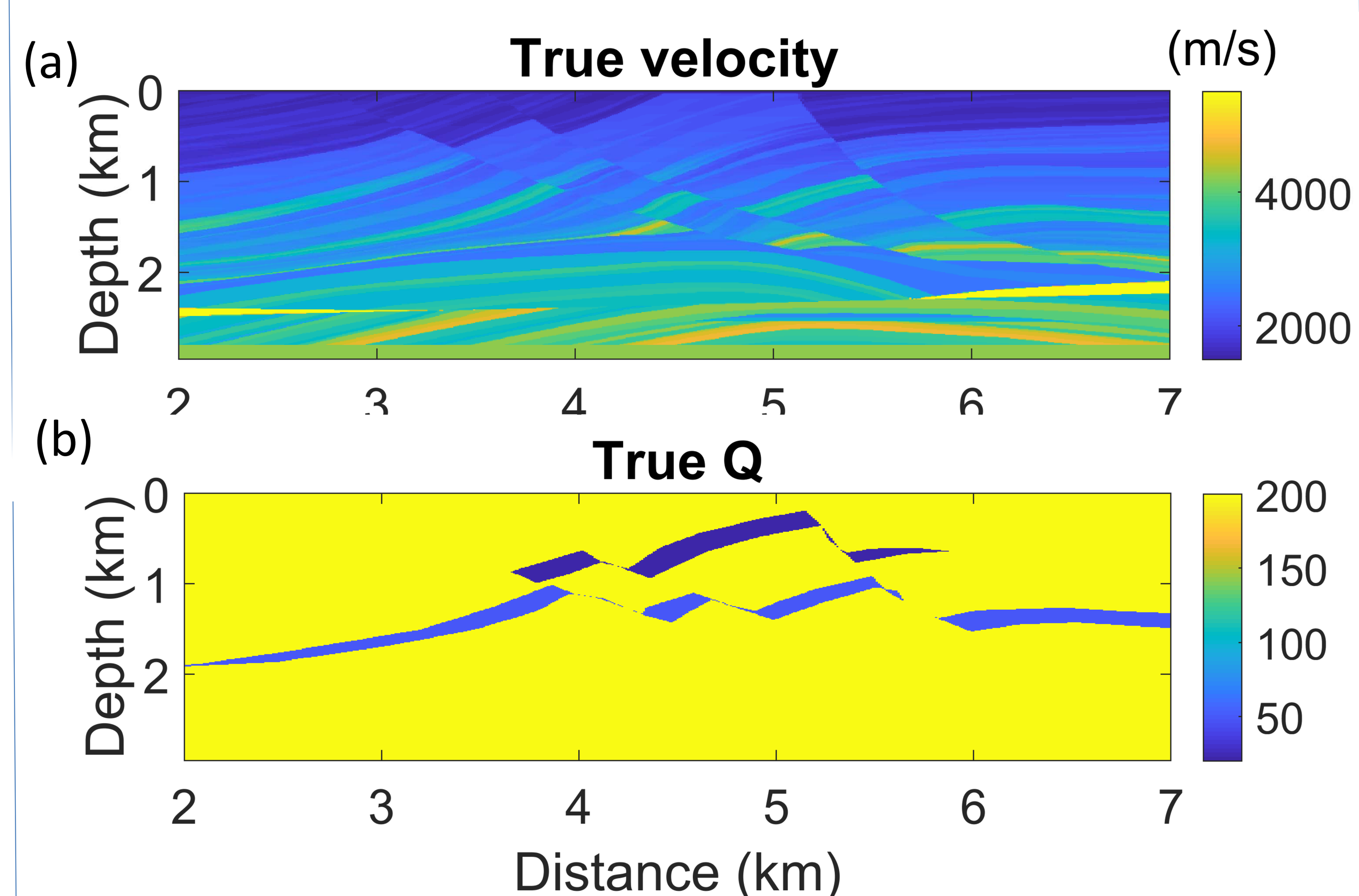

Figure 1: (a) True velocity model, (b) True Q .

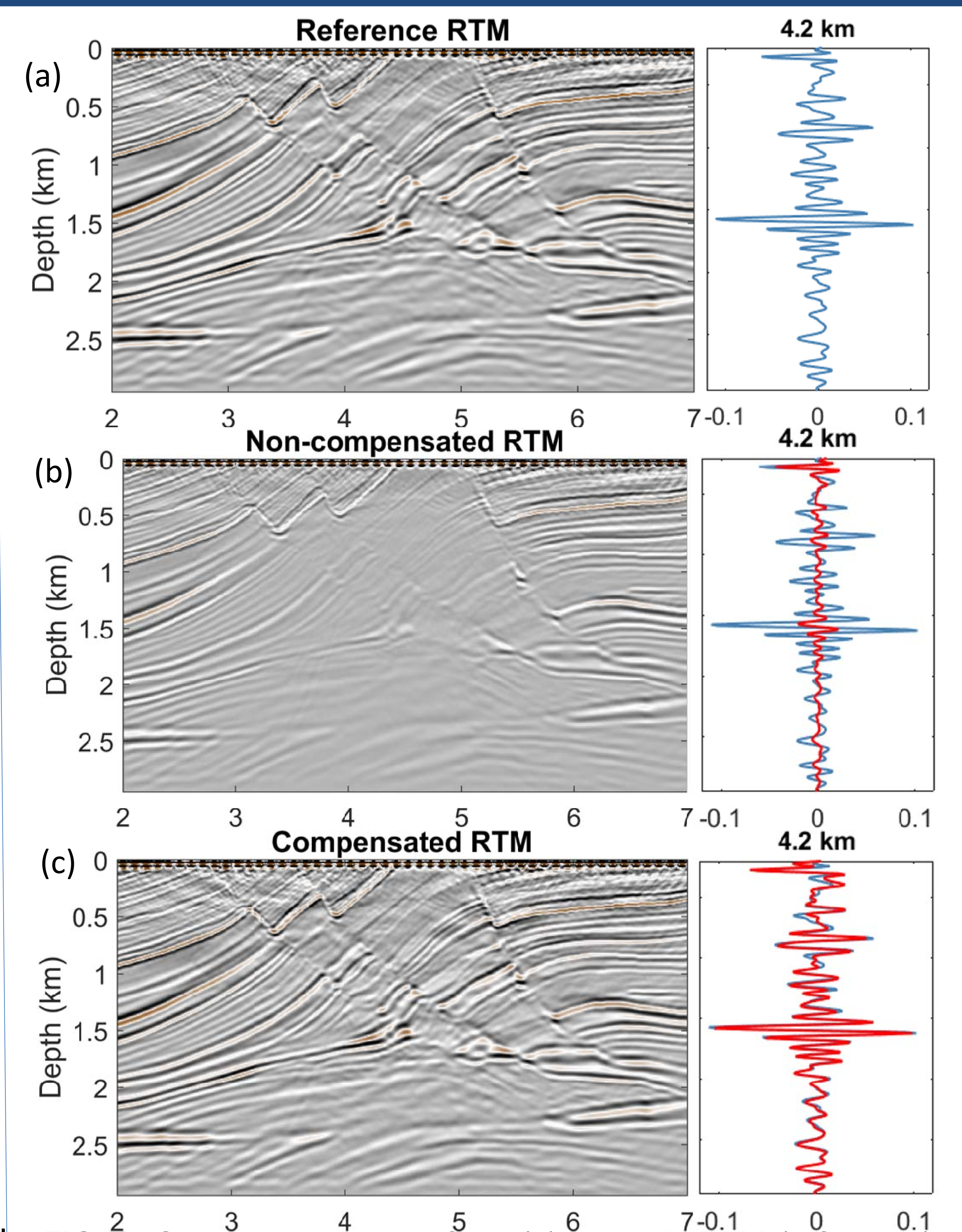

FIG. 3: Comparison among from (a) acoustic RTM (reference), (b) acoustic RTM with viscoacoustic data, and (c) Q-RTM with viscoacoustic data. The right panels show the reference trace (blue line), non-compensated trace (red line), and compensated trace (green line)at the horizontal 4.2 km. The compensated case agree with the reference image very well.

Conclusions

We have presented a viscoacoustic RTM imaging algorithm in tilted TI media based on the time-domain constant-Q wave propagation involving a series of standard linear solid mechanisms that can mitigate the attenuation and dispersion effects in the migrated images. The phase dispersion and amplitude attenuation operators in Q-RTM approach are separated, and the compensation operators are constructed by reversing the sign of the attenuation operator without changing the sign of the dispersion operator.

Acknowledgments

The authors thank the sponsors of CREWES for continued support. This work was funded by Mitacs, CREWES industrial sponsors and NSERC through the grant CRDPJ 461179-13.