

[0010] It is desirable to develop RTM methods that compensate for the absorption effects in TTI medium to obtain enhanced images of structures under complex geological regions with strong velocity contrast and substantial attenuation.

SUMMARY

[0011] According to various embodiments, visco-acoustic wave propagation in a TTI medium compensates for the anelastic effects to correct the frequency-dependent energy attenuation and phase distortion caused in the overburden.

[0012] According to an aspect, there is a method for obtaining an image of an explored underground formation. The method includes obtaining survey data carrying structural information of the explored formation, generating initial velocity and absorption models of the explored formation based on the survey data, and updating the initial velocity and absorption models while also determining Thomsen anisotropy parameters depending on tilt angle and azimuth angle of a tilted transverse isotropy, TTI, symmetry axis, using a visco-acoustic reverse time migration, RTM, wherein the visco-acoustic RTM includes calculating a backward propagated receiver wavefield at each subsurface point $\vec{x}$ as $\tilde{p}(\vec{x}, \omega) = \left| \frac{\tilde{p}_a(\vec{x}, \omega)}{\tilde{w}(\vec{x}, \omega)} \right|^2 \tilde{w}(\vec{x}, \omega)$, where $\tilde{w}(\vec{x}, \omega)$ is a field obtained by solving a visco-acoustic TTI wave equation in a conjugate medium, and $\tilde{p}_a(\vec{x}, \omega)$ is a wavefield obtained by solving an acoustic TTI wave equation in a lossless medium.

[0013] According to another aspect, there is a survey data processing apparatus configured to obtain an image of an explored underground formation. The apparatus

includes a communication interface and a data processing unit. The communication interface is configured to obtain survey data carrying structural information of the explored formation. The data processing unit is configured to generate initial velocity and absorption models of the explored formation based on the survey data, and to update the initial velocity and absorption models while also determining Thomsen anisotropy parameters depending on tilt angle and azimuth angle

of a tilted transverse isotropy, TTI, symmetry axis, using a visco-acoustic reverse time migration, RTM, wherein the visco-acoustic RTM includes calculating a backward propagated receiver wavefield at each subsurface point $\vec{x}$ as

$$\tilde{p}(\vec{x}, \omega) = \left| \frac{\tilde{p}_a(\vec{x}, \omega)}{\tilde{w}(\vec{x}, \omega)} \right|^2 \tilde{w}(\vec{x}, \omega), \text{ where } \tilde{w}(\vec{x}, \omega) \text{ is a field obtained by solving a visco-}$$

acoustic TTI wave equation in a conjugate medium, and $\tilde{p}_a(\vec{x}, \omega)$ is a wavefield obtained by solving an acoustic TTI wave equation in a lossless medium.

[0014] According to yet another aspect, there is a non-transitory computer readable recording medium storing executable codes which, when executed on a computer having access to survey data, make the computer to perform a method for obtaining an image of an explored underground formation. The method includes obtaining survey data carrying structural information of the explored formation, generating initial velocity and absorption models of the explored formation based on the survey data, and updating the initial velocity and absorption models while also determining Thomsen anisotropy parameters depending on tilt angle and azimuth angle of a tilted transverse isotropy, TTI, symmetry axis, using a visco-acoustic reverse time migration, RTM, , wherein the visco-acoustic RTM includes calculating a backward propagated receiver wavefield at each subsurface point $\vec{x}$ as

$$\tilde{p}(\vec{x}, \omega) = \left| \frac{\tilde{p}_a(\vec{x}, \omega)}{\tilde{w}(\vec{x}, \omega)} \right|^2 \tilde{w}(\vec{x}, \omega), \text{ where } \tilde{w}(\vec{x}, \omega) \text{ is a field obtained by solving a visco-}$$

acoustic TTI wave equation in a conjugate medium, and $\tilde{p}_a(\vec{x}, \omega)$ is a wavefield obtained by solving an acoustic TTI wave equation in a lossless medium.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate one or more embodiments and, together with the description, explain these embodiments. In the drawings:

[0016] Figure 1 illustrates seismic data acquisition;

[0017] Figure 2 illustrates Q estimation and compensation phases;

[0018] Figure 3 is an illustration of RTM;

[0019] Figure 4 is a flowchart of a Q TTI RTM method according to an embodiment;

WHAT IS CLAIMED IS:

1. A method for obtaining an image of an explored underground formation, the method comprising:
 - obtaining survey data carrying structural information of the explored formation;
 - generating initial velocity and absorption models of the explored formation based on the survey data; and
 - updating the initial velocity and absorption models while also determining Thomsen anisotropy parameters depending on tilt angle and azimuth angle of a tilted transverse isotropy, TTI, symmetry axis, using a visco-acoustic reverse time migration, RTM, wherein the visco-acoustic RTM includes calculating a backward propagated receiver wavefield at each subsurface point $\vec{x}$ as

$$\tilde{p}(\vec{x}, \omega) = \left| \frac{\tilde{p}_a(\vec{x}, \omega)}{\tilde{w}(\vec{x}, \omega)} \right|^2 \tilde{w}(\vec{x}, \omega)$$

where $\tilde{w}(\vec{x}, \omega)$ is a field obtained by solving a visco-acoustic TTI wave equation in a conjugate medium, and $\tilde{p}_a(\vec{x}, \omega)$ is a wavefield obtained by solving an acoustic TTI wave equation in a lossless medium.

2. The method of claim 1, wherein a propagation in the conjugate medium has a same phase velocity as in an original visco-acoustic medium, but a time-reversal propagation equation attenuates a backward propagating wavefield.

3. The method of claim 1 or 2, wherein the generating of the initial velocity and absorption models includes extracting amplitude variations as function of offset and frequency from the survey data.

4. The method of any one of claims 1 to 3, wherein the initial velocity and absorption models are generated using a Q tomography method.

5. The method of any one of claims 1 to 4, wherein the survey data is acquired during a marine seismic survey.

6. A survey data processing apparatus configured to obtain an image of an explored underground formation, the apparatus comprising:

a communication interface configured to obtain survey data carrying structural information of the explored formation; and

a data processing unit configured to generate initial velocity and absorption models of the explored formation based on the survey data; and

to update the initial velocity and absorption models while also determining Thomsen anisotropy parameters depending on tilt angle and azimuth angle of a tilted transverse isotropy, TTI, symmetry axis, using a visco-acoustic reverse time migration, RTM,

wherein the visco-acoustic RTM includes calculating a backward propagated receiver wavefield at each subsurface point $\vec{x}$ as

$$\tilde{p}(\vec{x}, \omega) = \left| \frac{\tilde{p}_a(\vec{x}, \omega)}{\tilde{w}(\vec{x}, \omega)} \right|^2 \tilde{w}(\vec{x}, \omega)$$

where $\tilde{w}(\vec{x}, \omega)$ is a field obtained by solving a visco-acoustic TTI wave equation in a conjugate medium, and $\tilde{p}_a(\vec{x}, \omega)$ is a wavefield obtained by solving an acoustic TTI wave equation in a lossless medium.

7. The apparatus of claim 6, wherein a propagation in the conjugate medium has a same phase velocity as in an original visco-acoustic medium, but a time-reversal propagation equation attenuates a backward propagating wavefield.

8. The apparatus of claim 6 or 7, wherein the data processing unit extracts amplitude variations as function of offset and frequency from the survey data to generate the initial velocity and absorption models.

9. The apparatus of any one of claims 6 to 8, wherein the data processing unit generates the initial velocity and absorption models using a Q tomography method.

10. The apparatus of any one of claims 6 to 9, wherein the survey data is acquired during a marine seismic survey.

11. A non-transitory computer readable recording medium storing executable codes which, when executed on a computer having access to survey data, make the computer to perform a method for obtaining an image of an explored underground formation, the method comprising:

obtaining the survey data which carries structural information of the explored formation;

generating initial velocity and absorption models of the explored formation based on the survey data; and

updating the initial velocity and absorption models together with determining Thomsen anisotropy parameters depending on tilt angle and azimuth angle of a tilted transverse isotropy, TTI, symmetry axis using a visco-acoustic reverse time migration, RTM,

wherein the visco-acoustic RTM includes calculating a backward propagated receiver wavefield at each subsurface point $\vec{x}$ as

$$\tilde{p}(\vec{x}, \omega) = \left| \frac{\tilde{p}_a(\vec{x}, \omega)}{\tilde{w}(\vec{x}, \omega)} \right|^2 \tilde{w}(\vec{x}, \omega)$$

where $\tilde{w}(\vec{x}, \omega)$ is a field obtained by solving a visco-acoustic TTI wave equation in a conjugate medium, and $\tilde{p}_a(\vec{x}, \omega)$ is a wavefield obtained by solving an acoustic TTI wave equation in a lossless medium.

12. The non-transitory computer readable recording medium of claim 11, wherein a propagation in the conjugate medium has a same phase velocity as in an

original visco-acoustic medium, but a time-reversal propagation equation attenuates a backward propagating wavefield.

13. The non-transitory computer readable recording medium of claim 11 or 12, wherein the generating of the initial velocity and absorption models includes extracting amplitude variations as function of offset and frequency from the survey data.

14. The non-transitory computer readable recording medium of any one of claims 11 to 13, wherein the initial velocity and absorption models are generated using a Q tomography method.

15. The non-transitory computer readable recording medium of any one of claims 11 to 14, wherein the survey data is acquired during a marine seismic survey.