CLAIMS

1. A method for transforming seismic data traces corresponding to at least one source position and a plurality of receiver positions in a seismic survey of a subsurface region into a near-surface earth model of elastic shear wave propagation velocity or other physical property of the earth derivable therefrom including shear modulus, said method comprising:

(a) dividing a near-surface part of the subsurface region into one or more cells;

(b) simultaneous solving for at least two types of surface-consistent components of the seismic traces, wherein a surface-consistent component characterizes filtering effects either of propagation of a seismic surface wave mode across a cell (a propagation filter), or due to generation of surface wave energy at a source location (a source filter) or due to receiving of source wave energy at a receiver location (a receiver filter), and wherein a "type" of surface-constant component is one of (i) a propagation filter for one surface wave mode, evaluated at all cells crossed by any of the seismic traces; (ii) a source filter, evaluated at all source locations for the seismic traces, or (iii) a receiver filter, evaluated at all receiver locations for the seismic traces; and

(c) choosing one or more of the surface-consistent components, and using them to compute by numerical inversion a near-surface earth model of shear wave velocity or other physical property of the earth derivable therefrom as a function of (x,y,z) location.

2. The method of claim 1, further comprising for some or all of the traces and corresponding seismic source and receiver locations, computing the raypath distance across each intervening cell from the source location to the receiver location, and wherein the solution for surface-consistent components optimizes said components by a single comparison or iterated comparisons of data traces from the seismic survey and surface-wave predictions computed using assumed or iteratively updated components along with the computed raypath distances.

3. The method of claim 2, further comprising repeating steps (a)-(b) at least once, wherein the cell division in (a) is changed to improve consistency between predicted and survey data waveforms.

4. The method of claim 1, wherein the components for each trace consist of a source component, a receiver component, and a component for each cell crossed in the raypath from the source to the receiver.

5. The method of claim 1, wherein at least two distinct modes are identified in the seismic data, and the surface-consistent components include parameters for multi-mode propagation of surface-waves.

6. The method of claim 5, wherein the distinct modes are identified from the data after the data are transformed into a frequency domain or a frequency-wavenumber domain.

7. The method of claim 1, wherein the surface-consistent components are also a function of azimuth or propagation direction.

8. The method of claim 1, wherein the surface-consistent components include parameters for velocity dispersion or attenuation.

9. The method of claim 1, wherein the numerical inversion is performed in (c) by minimizing a cost function involving the sum over a group of traces of the difference between a model expression, which is a function of said surface-consistent components, and the survey data.

10. The method of claim 1, wherein a model optimization algorithm is used in solving for said surface-consistent components, wherein the model is a model of a waveform for either a single ground roll mode or for multiple modes.

11. The method of claim 1, wherein solving for said surface-consistent components involves using one or more of constraints, damping, normalization, weights, and regularization.

12. The method of claim 1, wherein (c) comprises using said surface-consistent components to compute a surface wave waveform for comparison to corresponding recorded seismic data.

13. The method of claim 2, wherein the inversion in (c) is a nonlinear optimization problem in which the model is a near-surface velocity profile model, and parameters of the model include at least layer depths and layer shear modulus for near surface layers, and the inversion extracts velocity dispersion curves for each surface wave mode from the optimized surface-consistent components and compares them to velocity dispersion curves predicted by said velocity profile model.

14. The method of claim 1, wherein the seismic data are conditioned by windowing, by filtering, by cross-correlation filtering, or by cross-correlation, then followed by stacking or by transforming the data into a domain other than the space-time domain in which the data were recorded.

15. The method of claim 1, wherein the seismic data traces used correspond to a plurality of survey source locations, with each source impulse being recorded by a plurality of receivers.

16. The method of claim 1, wherein at least one of the surface-consistent components is a transfer function in frequency domain or an impulse response in time domain.

17. The method of claim 1, wherein the surface-consistent components are complex functions of frequency, i.e. functions having a real part and an imaginary part.

18. The method of claim 17, wherein the complex surface-consistent components include source amplitude and phase, and a complex slowness for each cell crossed by the trace raypath and for each ground-roll mode being treated.

19. The method of claim 1, further comprising using a computed near-surface earth model of shear modulus from (c) for engineering or design of improvements in or on the subsurface region.

20. A method for producing hydrocarbons from a subsurface region, comprising:

(a) obtaining a seismic image of the subsurface region including s-wave seismic data, wherein the s-wave data were processed for imaging using shear wave modulus values obtained using a method as described in claim 1, which is incorporated herein by reference; and

(b) drilling a well into the subsurface region based at least in part on the seismic image from (a), and producing hydrocarbons from the well.

21. A method for determining a near-surface earth model of elastic shear-wave propagation velocity from seismic data traces, comprising for a plurality of the traces estimating at least two surface-consistent transfer functions in frequency domain, or impulse responses in time domain, that represent changes in seismic surface wave waveforms as they propagate from source to receiver, and numerically inverting one or more of the surface-consistent transfer functions or impulse responses to compute a near-surface earth model of elastic shear-wave propagation velocity as a function of (x,y,z) location.

CLAIMS

1. A method for transforming seismic data traces corresponding to at least one source position and a plurality of receiver positions in a seismic survey of a subsurface region into a near-surface earth model of elastic shear wave propagation velocity or other physical property of the earth derivable therefrom including shear modulus, said method comprising: (a) dividing a near surface part of the subsurface region into one or more cells, and computing source-to-receiver ray path distances for each cell for a plurality of the seismic data traces; (b) using the ray path distances, simultaneously solving, using a computer, for at least two types of surface-consistent components of the seismic traces, as functions of x and y location and frequency, wherein a surface-consistent component characterizes filtering effects either of propagation of a seismic surface wave mode across a cell (a propagation filter), or due to generation of surface wave energy at a source location (a source filter) or due to receiving of source wave energy at a receiver location (a receiver filter), and wherein a "type" of surface-constant component is one of (i) a propagation filter for one surface wave mode, evaluated at all cells crossed by any of the seismic traces; (ii) a source filter, evaluated at all source locations for the seismic traces, or (iii) a receiver filter, evaluated at all receiver locations for the seismic traces; and (c) choosing one or more of the surface-consistent components, and using them to compute by numerical inversion, using a computer, a near-surface earth model of shear wave velocity or other physical property of the earth derivable therefrom as a function of (x,y,z) location.

2. The method of claim 1, further comprising for some or all of the traces and corresponding seismic source and receiver locations, computing the raypath distance across each intervening cell from the source location to receiver location, and wherein the solution for surface-consistent components optimizes said components by a single comparison or iterated comparisons of data traces from the seismic survey and surface-wave predictions computed using assumed or iteratively updated components along with the computed raypath distances.

3. The method of claim 2, further comprising repeating steps (a)-(b) at least once, wherein the cell division in (a) is changed to improve consistency between predicted and survey data waveforms.

4. The method of claim 1, wherein the components for each trace consist of a source component, a receiver component, and a component for each cell crossed in the raypath from the source to the receiver.

5. The method of claim 1, wherein at least two distinct modes are identified in the seismic data, and

the surface-consistent components include parameters for multi-mode propagation of surface-waves.

6. The method of claim 5, wherein the distinct modes are identified from the data after the data are transformed into a frequency domain or a frequency-wavenumber domain.

7. The method of claim 1, wherein the surface-consistent components are also a function of azimuth or propagation direction.

8. The method of claim 1, wherein the surface-consistent components include parameters for velocity dispersion or attenuation.

9. The method of claim 1, wherein the numerical inversion is performed in (c) by minimizing a cost function involving the sum over a group of traces of the difference between a model expression, which is a function of said surface-consistent components, and the survey data.

10. The method of claim 1, wherein a model optimization algorithm is used in solving for said surface-consistent components, wherein the model is a model of a waveform for either a single ground roll mode or for multiple modes.

11. The method of claim 1, wherein solving for said surface-consistent components involves using one or more of constraints, damping, normalization, weights, and regularization.

12. The method of claim 1, wherein (c) comprises using said surface-consistent components to compute a surface wave waveform for comparison to corresponding recorded seismic data.

13. The method of claim 2, wherein the inversion in (c) is a nonlinear optimization problem in which the model is a near-surface velocity profile model, and parameters of the model include at least layer depths and layer shear modulus for near surface layers, and the inversion extracts velocity dispersion curves for each surface wave mode from the optimized surface-consistent components and compares them to velocity dispersion curves predicted by said velocity profile model.

14. The method of claim 1, wherein the seismic data are conditioned by windowing, by filtering, by cross-correlation filtering, or by cross-correlation, then followed by stacking or by transforming the data into a domain other than the space-time domain in which the data were recorded.

15. The method of claim 1, wherein the seismic data traces used correspond to a plurality of survey source locations, with each source impulse being recorded by a plurality of receivers.

16. The method of claim 1, wherein at least one of the surface-consistent components is a transfer function in frequency domain or an impulse response in time domain.

17. The method of claim 1, wherein the surface-consistent components are complex functions of frequency, i.e. functions having a real part and an imaginary part.

18. The method of claim 17, wherein the complex surface-consistent components include source amplitude and phase, and a complex slowness for each cell crossed by the trace raypath and for each ground-roll mode being treated.

19. The method of claim 1, further comprising using a computed near-surface earth model of shear modulus from (c) for engineering or design of improvements in or on the subsurface region.

20. The method of claim 1, further comprising using a computed near-surface earth model of shear wave velocity from (c) for hydrocarbon assessment of, or extraction of hydrocarbons from, the subsurface region.

21. A method for producing hydrocarbons from a subsurface region, comprising:

(a) obtaining a seismic image of the subsurface region including s-wave seismic data, wherein traces from the s-wave data were processed for imaging using shear wave modulus values obtained using a method comprising:

dividing a near surface part of the subsurface region into one or more cells, and computing source-to-receiver ray path distances for each cell for a plurality of the seismic data traces;

using the ray path distances, simultaneously solving, using a computer, for at least two types of surface-consistent components of the seismic traces, as functions of x and y location and frequency, wherein a surface-consistent component characterizes filtering effects either of propagation of a seismic surface wave mode across a cell (a propagation filter), or due to generation of surface wave energy at a source location (a source filter) or due to receiving of source wave energy at a receiver location (a receiver filter), and wherein a "type" of surface-constant component is one of (i) a propagation filter for one surface wave mode, evaluated at all cells crossed by any of the seismic traces; (ii) a source filter, evaluated at all source

locations for the seismic traces, or (iii) a receiver filter, evaluated at all receiver locations for the seismic traces; and

choosing one or more of the surface-consistent components, and using them to compute by numerical inversion, using a computer, a near-surface earth model of shear wave modulus as a function of (x,y,z) location; and (b) drilling a well into the subsurface region based at least in part on the seismic image from (a), and producing hydrocarbons from the well.

22. A method for determining a near-surface earth model of elastic shear-wave propagation velocity from seismic data traces, comprising for a plurality of the traces computing source-receiver ray path distances and using them to simultaneously solve for at least two surface-consistent transfer functions in x-y-frequency domain, or impulse responses in x-y-time domain, that represent changes in seismic surface wave waveforms as they propagate from source to receiver, computing one or more velocity dispersion curves from the surface-consistent transfer functions or impulse responses, and numerically inverting the one or more velocity dispersion curves to compute a near-surface earth model of elastic shear-wave propagation velocity as a function of (x,y,z) location, wherein the computing, simultaneous solving, and numerically inverting are performed using a computer.

23. The method of claim 1, further comprising isolating surface waves in the seismic data traces by time windowing, choice of traces, or filtering, and using the surface waves in (b).