

CLAIMS

1. A computer-implemented method for accelerating convergence of iterative inversion of seismic data to obtain a model of one or more physical parameters in a subsurface region, comprising using local cost function optimization, wherein an assumed or current model is updated to reduce misfit between the seismic data and model-simulated data, wherein the frequency spectrum of the updated model is controlled in a first iteration and thereafter to match a known or estimated frequency spectrum for the subsurface region, wherein the controlling of the frequency spectrum comprises applying a spectral-shaping filter to both the seismic data and to a source wavelet used to generate the model-simulated data, or to a gradient of the cost function in at least a first iteration, said spectral-shaping filter being derived according to a criterion that the spectrum of a gradient of the cost function with respect to one of the one or more physical parameters, after application of the spectral-shaping filter to both the seismic data and to a source wavelet, should match the known or estimated frequency spectrum for the subsurface region.
2. The method of claim 1, wherein updating the assumed or current model comprises computing a gradient of the cost function with respect to one of the one or more physical parameters, and then applying a spectral-shaping filter to the gradient in at least the first iteration; and wherein the model-simulated data are generated using a source wavelet having a frequency spectrum $W(f)$ that satisfies $D(f) \approx f I_p(f) W(f)$, where $D(f)$ is an average frequency spectrum of the seismic data, f is frequency, and $I_p(f)$ is an average frequency spectrum of P-impedance in the subsurface region or is approximated by a frequency spectrum of a different elastic parameter of the subsurface region; and wherein said known or estimated frequency spectrum is $I_p(f)$.
3. The method of claim 2, wherein the spectral-shaping filter $H(f)$ is determined by dividing a known or estimated frequency spectrum $S(f)$ in the subsurface region for said one of the one or more physical parameters by the gradient's spectrum before shaping $G(f)$, where $G(f)$ is a frequency spectrum of the gradient of the cost function with respect to one of the one or more physical parameters.
4. The method of claim 2, wherein the spectral-shaping filter varies with time.
5. The method of claim 1, wherein the known or estimated frequency spectrum for the subsurface region is obtained by averaging spectra of well logs from the subsurface region.

6. The method of claim 5, wherein models of at least two physical parameters are simultaneously obtained, and a known or estimated frequency spectrum for each physical parameter is obtained by averaging spectra of well logs measuring or corresponding to the physical parameter.

7. The method of claim 1, wherein models of at least two physical parameters are simultaneously obtained, and the frequency spectrum of each updated model in the first iteration and thereafter is controlled to match a known or estimated frequency spectrum of the corresponding physical parameter in the subsurface region.

8. The method of claim 7, wherein updating the assumed or current model of a particular physical parameter (denoted by index i) comprises computing a gradient with respect to that particular physical parameter (V_i) of the cost function, and then applying a spectral-shaping filter to the gradient, wherein the spectral-shaping filter is tailored to the particular physical parameter and a known or estimated frequency spectrum, $S_i(f)$, of the particular physical parameter in the subsurface region.

9. The method of claim 8, wherein the spectral-shaping filter is determined by dividing $S_i(f)$ by the gradient's spectrum before shaping.

10. The method of claim 8, wherein the spectral-shaping filter varies with time.

11. The method of claim 1, wherein the one or more physical parameters are selected from a group consisting of P-impedance, S-impedance, density, P-velocity, and S-velocity.

12. The method of claim 1, wherein the model-simulated data are generated using a seismic source wavelet having a frequency spectrum $W(f)$ satisfying, to within a proportionality constant, the following equation:

$$D(f) = I_p(f)W(f)$$

where f is frequency, $D(f)$ is average frequency spectrum of the seismic data, and $I_p(f)$ is average frequency spectrum for P-impedance in the subsurface region or an approximation thereof based on a frequency spectrum of another elastic parameter.

13. The method of claim 12, wherein $D(f)$ and $I_p(f)$ are average spectra, meaning averaged over the subsurface region.

14. A computer program product, comprising a non-transitory computer usable medium having a computer readable program code embodied therein, said computer readable program code adapted to be executed to implement a method for inverting seismic data to obtain a model of one or more physical parameters in a subsurface region, said method comprising using iterative inversion with local cost function optimization, wherein an assumed or current model is updated to reduce misfit between the seismic data and model-simulated data, wherein the updated model's frequency spectrum in each iteration is controlled to match an input known or estimated frequency spectrum for the subsurface region; wherein the controlling of the frequency spectrum in each iteration comprises applying a spectral-shaping filter to both the seismic data and to a source wavelet used to generate the model-simulated data, or to a gradient of the cost function in at least a first iteration, said spectral-shaping filter being derived according to a criterion that the spectrum of a gradient of the cost function with respect to one of the one or more physical parameters, after application of the spectral-shaping filter to both the seismic data and to a source wavelet, should match the known or estimated frequency spectrum for the subsurface region.

15. The method of claim 1, wherein the cost function is a cross-correlation between the seismic data and the model-simulated data, and the optimization maximizes the cost function after the frequency spectrum control is applied to the seismic data and the model simulated data.

16. The method of claim 15, wherein source encoding is used on the seismic data and in the model simulation, and a plurality of encoded sources are simultaneously inverted.

17. The method of claim 16, wherein the encoding is changed for at least one iteration of the inversion.

18. The method of claim 1, wherein the cost function is an envelope function of a cross-correlation between the seismic data and the model-simulated data, and the optimization maximizes the cost function.

19. The method of claim 18, wherein source encoding is used on the seismic data and in the model simulation, and a plurality of encoded sources are inverted in a single inversion.

20. The method of claim 19, wherein the encoding is changed for at least one iteration of the inversion.

21. The method of claim 1, wherein the source wavelet before application of the spectral-shaping filter is chosen to have a frequency spectrum $W(f)$ that satisfies $D(f) \approx f l_p(f) W(f)$, where $D(f)$ is an average frequency spectrum of the seismic data, f is frequency, and where said known or estimated frequency spectrum for the subsurface region $l_p(f)$, is an average frequency spectrum of P-impedance in the subsurface region or is approximated by a frequency spectrum of a different elastic parameter of the subsurface region.

22. The method of claim 21, wherein the spectral-shaping filter satisfies

$$H(f) = \{f^{1/2} l_p(f)\} / \{a^{1/2}(f) D(f)\}$$

where $A\{f\}$ is a frequency-dependent factor determined such that

$$G(f) = A\{f\} W(f) D(f)$$

where $G\{f\}$ is a frequency spectrum of a gradient of the cost function with respect to one of the one or more physical parameters.

CLAIMS

1. A computer-implemented method for accelerating convergence of iterative inversion of seismic data to obtain a model of one or more physical parameters in a subsurface region, comprising using local cost function optimization, wherein an assumed or current model is updated to reduce misfit between the seismic data and model-simulated data, wherein the frequency spectrum of the updated model is controlled in a first iteration and thereafter to match a known or estimated frequency spectrum for the subsurface region, wherein the controlling of the frequency spectrum comprises applying a spectral-shaping filter to both the seismic data and to a source wavelet used to generate the model-simulated data, or to a gradient of the cost function in at least a first iteration, said spectral-shaping filter being derived according to a criterion that the spectrum of the gradient of the cost function should match the known or estimated frequency spectrum for the subsurface region.
2. The method of claim 1, wherein updating the assumed or current model comprises computing a gradient of the cost function with respect to one of the one or more physical parameters, and then applying a spectral-shaping filter to the gradient in at least the first iteration; and wherein the model-simulated data are generated using a source wavelet having a frequency spectrum $W(f)$ that satisfies $D(f) \approx I_p(f) W(f)$, where $D(f)$ is an average frequency spectrum of the seismic data, f is frequency, and $I_p(f)$ is an average frequency spectrum of P-impedance in the subsurface region or is approximated by a frequency spectrum of a different elastic parameter of the subsurface region; and wherein said known or estimated frequency spectrum is $I_p(f)$.
3. The method of claim 2, wherein the spectral-shaping filter $H(f)$ is determined by dividing a known or estimated frequency spectrum $S(f)$ in the subsurface region for said one of the one or more physical parameters by the gradient's spectrum before shaping $G(f)$, where $G(f)$ is a frequency spectrum of the gradient of the cost function with respect to one of the one or more physical parameters.
4. The method of claim 2, wherein the spectral-shaping filter varies with time.
5. The method of claim 1, wherein the known or estimated frequency spectrum for the subsurface region is obtained by averaging spectra of well logs from the subsurface region.
6. The method of claim 5, wherein models of at least two physical parameters are

simultaneously obtained, and a known or estimated frequency spectrum for each physical parameter is obtained by averaging spectra of well logs measuring or corresponding to the physical parameter.

7. The method of claim 1, wherein models of at least two physical parameters are simultaneously obtained, and the frequency spectrum of each updated model in the first iteration and thereafter is controlled to match a known or estimated frequency spectrum of the corresponding physical parameter in the subsurface region.

8. The method of claim 7, wherein updating the assumed or current model of a particular physical parameter (denoted by index i) comprises computing a gradient with respect to that particular physical parameter (V_i) of the cost function, and then applying a spectral-shaping filter to the gradient, wherein the spectral-shaping filter is tailored to the particular physical parameter and a known or estimated frequency spectrum, $S_i(f)$, of the particular physical parameter in the subsurface region.

9. The method of claim 8, wherein the spectral-shaping filter is determined by dividing $S_i(f)$ by the gradient's spectrum before shaping.

10. The method of claim 8, wherein the spectral-shaping filter varies with time.

11. The method of claim 1, wherein the one or more physical parameters are selected from a group consisting of P-impedance, S-impedance, density, P-velocity, and S-velocity.

12. The method of claim 1, wherein the model-simulated data are generated using a seismic source wavelet having a frequency spectrum $W(f)$ satisfying, to within a proportionality constant, the following equation:

$$D(f) = f I_p(f) W(f)$$

where f is frequency, $D(f)$ is average frequency spectrum of the seismic data, and $I_p(f)$ is average frequency spectrum for P-impedance in the subsurface region or an approximation thereof based on a frequency spectrum of another elastic parameter.

13. The method of claim 12, wherein $D(f)$ and $I_p(f)$ are average spectra, meaning averaged over the subsurface region.

14. A computer program product, comprising a non-transitory computer usable medium having a computer readable program code embodied therein, said computer readable program code adapted to be executed to implement a method for inverting seismic data to obtain a model of one or more physical parameters in a subsurface region, said method comprising using iterative inversion with local cost function optimization, wherein an assumed or current model is updated to reduce misfit between the seismic data and model-simulated data, wherein the updated model's frequency spectrum in each iteration is controlled to match an input known or estimated frequency spectrum for the subsurface region; wherein the controlling of the frequency spectrum in each iteration comprises applying a spectral-shaping filter to both the seismic data and to a source wavelet used to generate the model-simulated data, or to a gradient of the cost function in at least a first iteration, said spectral-shaping filter being derived according to a criterion that the spectrum of the gradient of the cost function should match the known or estimated frequency spectrum for the subsurface region.

15. The method of claim 1, wherein the cost function is a cross-correlation between the seismic data and the model-simulated data, and the optimization maximizes the cost function after the frequency spectrum control is applied to the seismic data and the model simulated data.

16. The method of claim 15, wherein source encoding is used on the seismic data and in the model simulation, and a plurality of encoded sources are simultaneously inverted.

17. The method of claim 16, wherein the encoding is changed for at least one iteration of the inversion.

18. The method of claim 1, wherein the cost function is an envelope function of a cross-correlation between the seismic data and the model-simulated data, and the optimization maximizes the cost function.

19. The method of claim 18, wherein source encoding is used on the seismic data and in the model simulation, and a plurality of encoded sources are inverted in a single inversion.

20. The method of claim 19, wherein the encoding is changed for at least one iteration of the inversion.

21. The method of claim 1, wherein the source wavelet before application of the spectral-shaping filter is chosen to have a frequency spectrum $W(f)$ that satisfies

$D(f) \approx f l_p(f) W(f)$, where $D(f)$ is an average frequency spectrum of the seismic data, f is frequency, and where said known or estimated frequency spectrum for the subsurface region $l_p(f)$, is an average frequency spectrum of P-impedance in the subsurface region or is approximated by a frequency spectrum of a different elastic parameter of the subsurface region.

22. The method of claim 21, wherein the spectral-shaping filter satisfies

$$H(f) = \{f^{1/2} l_p(f)\} / \{a^{1/2}(f) D(f)\}$$

where $A(f)$ is a frequency-dependent factor determined such that

$$G(f) = A(f) W(f) D(f)$$

where $G(f)$ is a frequency spectrum of a gradient of the cost function with respect to one of the one or more physical parameters.