CLAIMS

1. A method for determining a model of a physical property in a subsurface region from inversion of seismic data, acquired from a seismic survey of the subsurface region, or from reverse time migration of seismic images from the seismic data, said method comprising determining a seismic resolution volume for the physical property and using it as a multiplicative scale factor

in computations performed on a computer to either

convert a gradient of data misfit in an inversion, or

compensate reverse-time migrated seismic images,

to obtain the model of the physical property or an update to an assumed model.

2. The method of claim 1, further comprising multiplying the gradient of data misfit or the reverse time migrated seismic images by additional scale factors including a source illumination factor, a receiver illumination factor, and a background medium properties factor to then obtain the model of the physical property or an update to an assumed model.

3. The method of claim 1, wherein the seismic resolution volume is determined by ray tracing using velocity of a background medium model and using an assumed function of frequency for a seismic wavelet.

4. The method of claim 2, wherein the model is determined from inversion of seismic data, said method further comprising:

assuming an initial model of the subsurface region specifying a model parameter at discrete cell locations in the subsurface region;

forming a mathematical objective function to measure misfit between measured seismic data and model-calculated seismic data;

selecting a mathematical relationship that gives an adjustment, i.e. update, to the initial model that would reduce the misfit, said mathematical relationship relating said

adjustment to a scaled gradient of the objective function, said gradient being with respect to said model parameter, the scaling comprising the four scale factors, i.e.

the seismic resolution volume factor,

the source illumination factor,

the receiver illumination factor, and

the background medium properties factor,

all of which appear in the mathematical relationship as multiplicative factors that scale the gradient of the objective function to yield the adjustment to the model parameter; and

using a computer to compute the adjustment from the mathematical relationship, and then updating the initial model with the computed adjustment.

5. The method of claim 4, wherein the physical property, i.e. the model parameter, is either bulk modulus or density, or a combination of bulk modulus and density.

6. The method of claim 4, wherein the mathematical relationship depends upon the physical property.

7. The method of claim 4, wherein the background medium properties factor comprises bulk modulus raised to the fourth power divided by density squared when the physical property is bulk modulus, and comprises density squared when the physical property is density.

8. The method of claim 4, wherein the receiver illumination factor when the physical property is bulk modulus is approximated by $(1/8\pi)(\rho_b(\mathbf{r}_g)/\rho_b(\mathbf{r}))$, where $\rho_b(\mathbf{r})$ is background density at location $\mathbf{r}$ and $\mathbf{r}_g$ is the receiver's location; and the receiver illumination factor when the physical property is density, $I_{\rho,g}(\mathbf{r})$, is approximated by:

$$I_{\rho,g}(\mathbf{r}) = \frac{\rho_b(\mathbf{r}_g)}{\rho_b(\mathbf{r})} \frac{1}{8\pi v_p^2(\mathbf{r})}.$$

where $v_p(\mathbf{r})$ is velocity at location $\mathbf{r}$.

9. The method of claim 4, further comprising repeating the method for at least one iteration, where in the initial model is replaced by the updated model from the previous iteration.

10. The method of claim 9, wherein the objective function's functional form and the mathematical relationship's functional form are unchanged from one iteration to a next iteration.

11. The method of claim 4, wherein the adjustment to the initial model is computed by minimizing the objective function using the objective function's Hessian resulting in an Hessian matrix, wherein off-diagonal elements of the Hessian matrix are ignored when outside of a seismic resolution volume.

12. The method of claim 11, wherein off-diagonal elements of the Hessian matrix within a seismic resolution volume are assumed to be equal to a corresponding diagonal element, resulting in computing only diagonal elements.

13. The method of claim 2, wherein the receiver illumination factor when the physical property is bulk modulus is approximated by an integral of a Green's function in free space over a surface defined by the seismic survey's receiver spread.

14. The method of claim 4, wherein the receiver illumination factor when the physical property is density is approximated by an integral of a gradient of a Green's function in free space over a surface defined by the seismic survey's receiver spread.

15. The method of claim 1, wherein the seismic resolution volume is approximated as a sphere based on an assumption of uniform wavenumber coverage.

16. The method of claim 4, further comprising using the updated model to precondition the gradient in an iterative optimization technique.

17. The method of claim 2, wherein the model is determined from reverse time migration of seismic images from the seismic data.

18. The method of claim 17, wherein the physical property is bulk modulus.

19. The method of claim 17, wherein the background medium properties factor comprises bulk modulus squared divided by density.

20. The method of claim 17, wherein the receiver illumination factor is approximated by $(1/8\pi)(\rho_b(\mathbf{r}_g)/\rho_b(\mathbf{r}))$, where $\rho_b(\mathbf{r})$ is background density at location $\mathbf{r}$ and $\mathbf{r}_g$ is the receiver's location.

21. The method of claim 17, wherein the migrated images' seismic amplitudes are converted into difference bulk modulus or difference compressional wave velocity.

The invention claimed is:

1. A method for determining a model of a physical property in a subsurface region from inversion of seismic data, acquired from a seismic survey of the subsurface region, or from reverse time migration of seismic images from the seismic data, said method comprising determining a seismic resolution volume for the physical property and using it as a multiplicative scale factor in computations performed on a computer to either convert a gradient of data misfit in an inversion, or compensate reverse-time migrated seismic images, to obtain the model of the physical property or an update to an assumed model.

2. The method of claim 1, further comprising multiplying the gradient of data misfit or the reverse time migrated seismic images by additional scale factors including a source illumination factor, a receiver illumination factor, and a background medium properties factor to then obtain the model of the physical property or an update to an assumed model.

3. The method of claim 1, wherein the seismic resolution volume is determined by ray tracing using velocity of a background medium model and using an assumed function of frequency for a seismic wavelet.

4. The method of claim 2, wherein the model is determined from inversion of seismic data, said method further comprising: assuming an initial model of the subsurface region specifying a model parameter at discrete cell locations in the subsurface region; forming a mathematical objective function to measure misfit between measured seismic data and model-calculated seismic data; selecting a mathematical relationship that gives an adjustment, i.e. update, to the initial model that would reduce the misfit, said mathematical relationship relating said adjustment to a scaled gradient of the objective function, said gradient being with respect to said model parameter, the scaling comprising the four scale factors, i.e. the seismic resolution volume factor, the source illumination factor, the receiver illumination factor, and the background medium properties factor, all of which appear in the mathematical relationship as multiplicative factors that scale the gradient of the objective function to yield the adjustment to the model parameter; and using a computer to compute the adjustment from the mathematical relationship, and then updating the initial model with the computed adjustment.

5. The method of claim 4, wherein the physical property, i.e. the model parameter, is either bulk modulus or density, or a combination of bulk modulus and density.

6. The method of claim 4, wherein the mathematical relationship depends upon the physical property.

7. The method of claim 4, wherein the background medium properties factor comprises bulk modulus raised to the fourth power divided by density squared when the physical property is bulk modulus, and comprises density squared when the physical property is density.

8. The method of claim 4, wherein the receiver illumination factor when the physical property is bulk modulus is approximated by $(1/8\pi)(\rho_b(r_g)/\rho_b(r))$, where $\rho_b(r)$ is background density at location r and r_g is the receiver's location; and the receiver illumination factor when the physical property is density, $I_{\rho,g}(r)$, is approximated by:

$$I_{\rho,g}(r) = \frac{\rho_b(r_g)}{\rho_b(r)} \frac{1}{8\pi v_p^2(r)},$$

where $v_p(r)$ is velocity at location r.

9. The method of claim 4, further comprising repeating the method for at least one iteration, where in the initial model is replaced by the updated model from the previous iteration.

10. The method of claim 9, wherein the objective function's functional form and the mathematical relationship's functional form are unchanged from one iteration to a next iteration.

11. The method of claim 4, wherein the adjustment to the initial model is computed by minimizing the objective function using the objective function's Hessian resulting in an Hessian matrix, wherein off-diagonal elements of the Hessian matrix are ignored when outside of a seismic resolution volume.

12. The method of claim 11, wherein off-diagonal elements of the Hessian matrix within a seismic resolution volume are assumed to be equal to a corresponding diagonal element, resulting in computing only diagonal elements.

13. The method of claim 2, wherein the physical property is bulk modulus and the receiver illumination factor is approximated by an integral of a Green's function in free space over a surface defined by the survey's receiver spread.

14. The method of claim 4, wherein the physical property is density and the receiver illumination factor is approximated by an integral of a gradient of a Green's function in free space over a surface defined by the survey's receiver spread.

15. The method of claim 1, wherein the seismic resolution volume is approximated as a sphere based on an assumption of uniform wavenumber coverage.

16. The method of claim 4, further comprising using the updated model to precondition the gradient in an iterative optimization technique.

17. The method of claim 2, wherein the model is determined from reverse time migration of seismic images from the seismic data.

18. The method of claim 17, wherein the physical property is bulk modulus.

19. The method of claim 17, wherein the background medium properties factor comprises bulk modulus squared divided by density.

20. The method of claim 17, wherein the receiver illumination factor is approximated by $(1/8\pi)(\rho_b(r_g)/\rho_b(r))$, where $\rho_b(r)$ is background density at location r and r_g is the receiver's location.

21. The method of claim 17, wherein the migrated images seismic amplitudes are converted into difference bulk modulus or difference compressional wave velocity.