CLAIMS

What is claimed is:

1. A method for processing seismic traces to produce an image of a subsurface area, said method comprising:

receiving a series of seismic traces related to the subsurface area and recorded by one or more seismic receivers, wherein the ~~one or more~~series of seismic ~~sources~~ traces are originally generated by a source;

applying a 3-dimensional (3D) phase encoding function to the series of seismic traces, at least a portion of said seismic traces comprise signals reflected by geological interfaces of the subsurface area;

~~applying a 3-dimensional (3D) harmonic-source reverse time migration of the series of seismic traces encoded with the phase encoding function;~~

computing a forward wavefield by solving a first wave equation that is modified to include the phase encoding function;

computing a backward wavefield by solving a second wave equation that is modified by a 3D harmonic-source reverse time migration of the series of seismic traces encoded with the phase encoding function; and

cross-correlating the forward wavefield with the backward wavefield to generate an image of the subsurface.

2. The method of Claim 1, wherein the phase encoding function in the time domain is given by

$$\cos(k_x x_s + k_y y_s)\delta(t) - \sin(k_x x_s + k_y y_s)\frac{2}{t},$$

where k_x and k_y are wavenumbers for axes X and Y, x_s and y_s are coordinates of a position of a source, t is a time when a wave generated by the source is recorded at a receiver, and δ is a delta function.

3. The method of Claim 1, wherein the forward wavefield p_f is computed by solving equation

$$\left(\frac{1}{c^2}\frac{\partial^2}{\partial t^2} - \nabla^2\right)p_F(\vec{x};t) = \left(\cos(k_x x_s + k_y y_s)\delta(t) - \frac{2}{t}\sin(k_x x_s + k_y y_s)\right)\delta(z),$$

where c is the speed of sound in the subsurface, k_x and k_y are wavenumbers for axes X and Y, x_s and y_s are coordinates of a position of a source, t is a time when a wave generated by the source is recorded at a receiver, z is a depth of the receiver, and δ is a delta function.

4. The method of Claim 1, wherein the backward wavefield p_b is computed by solving equation

$$\left(\frac{1}{c^2}\frac{\partial^2}{\partial t^2} - \nabla^2\right)p_B(\vec{x};t) = 0 \text{ and}$$
$$p_F(x,y,z=0;t) = h_{3D}(x,y;k_{xs}k_{ys};t),$$

where c is the speed of sound in the subsurface, h_{3D} is the 3D harmonic-source time-reverse migration, and t is the time.

5. The method of Claim 4, wherein the h_{3D} is given by

$$h_{3D}(x_r,y_r;k_x,k_y;t) = \int \hat{Q}(x_r,y_r;x_s,y_s;\omega)e^{i\,\mathrm{sgn}(\omega)(k_x x_s + k_y y_s)}e^{i\omega t}\,d\omega dx_s dy_s,$$

where $\hat{Q}(x_r,y_r;x_s,y_s;\omega)$ is the acquired seismic data indexed by shot and receiver locations, ω is the frequency, k_x and k_y are wavenumbers in X and Y, respectively, and $e^{i\,\mathrm{sgn}(\omega)(k_x x_s + k_y y_s)}e^{i\omega t}$ is the phase encoding function in the frequency domain.

6. The method of Claim 1, further comprising:

rendering the image of said subsurface area according to the following equation

$$R(\vec{x}) = \sum_{k_x,k_y}\int p_B(\vec{x};k_x,k_y;t)p_F(\vec{x};k_x,k_y;t)dt,$$

where R is the reflectivity of an interface in the subsurface area, k_x and k_y are wavenumbers on X and Y axes, p_b is backward wavefield, p_f is the forward wavefield, x is a spatial position and t is a corresponding time.

7. The method of Claim 1, wherein the cross-correlation comprises:

correlating a final wavefield in a forward propagation of the source with an initial wavefield in the backward propagation of one receiver.

8. The method of Claim 7, further comprising:

summing results of the cross-correlation to form a partial image volume for each shot; and

spatially summing image volumes for consecutive shot gathers are to produce a final pre-stack depth image.

9. A computing device for processing seismic traces to produce an image of a subsurface area, said computing device comprising:

a processor configured to,

receive a series of seismic traces related to the subsurface area and recorded by one or more seismic receivers, wherein the ~~one or more~~series of seismic ~~sources~~ traces are originally generated by a source;

apply a 3-dimensional (3D) phase encoding function to the series of seismic traces, at least a portion of said seismic traces comprise signals reflected by geological interfaces of the subsurface area;

~~apply a 3-dimensional (3D) harmonic-source reverse-time migration of the series of seismic traces encoded with the phase encoding function;~~

compute a forward wavefield by solving a first wave equation that is modified to include the phase encoding function;

compute a backward wavefield by solving a second wave equation that is modified by a 3D harmonic-source reverse time migration of the series of seismic traces encoded with the phase encoding function; and

cross-correlate the forward wavefield with the backward wavefield to generate an image of the subsurface.

10. The computing device of Claim 9, wherein the phase encoding function in the time domain is given by

$$\cos(k_x x_s + k_y y_s)\delta(t) - \sin(k_x x_s + k_y y_s)\frac{2}{t},$$

where k_x and k_y are wavenumbers for axes X and Y, x_s and y_s are coordinates of a position of a source, t is a time when a wave generated by the source is recorded at a receiver, and δ is a delta function.

11. The computing device of Claim 9, wherein the forward wavefield p_f is computed by solving equation

$$\left(\frac{1}{c^2}\frac{\partial^2}{\partial t^2} - \nabla^2\right)p_F(\vec{x};t) = \left(\cos(k_x x_s + k_y y_s)\delta(t) - \frac{2}{t}\sin(k_x x_s + k_y y_s)\right)\delta(z),$$

where c is the speed of sound in the subsurface, k_x and k_y are wavenumbers for axes X and Y, x_s and y_s are coordinates of a position of a source, t is a time when a wave generated by the source is recorded at a receiver, z is a depth of the receiver, and δ is a delta function.

12. The computing device of Claim 9, wherein the backward wavefield p_b is computed by solving equation

$$\left(\frac{1}{c^2}\frac{\partial^2}{\partial t^2} - \nabla^2\right)p_B(\vec{x};t) = 0 \text{ and}$$
$$p_F(x, y, z = 0; t) = h_{3D}(x, y; k_{xs}, k_{ys}; t),$$

where c is the speed of sound in the subsurface, h_{3D} is the 3D harmonic-source time-reverse migration, and t is the time.

13. The computing device of Claim 12, wherein the h_{3D} is given by

$$h_{3D}(x_r, y_r; k_x, k_y; t) = \int \hat{Q}(x_r, y_r; x_s, y_s; \omega)e^{i\,\mathrm{sgn}(\omega)(k_x x_s + k_y y_s)}e^{i\omega t}\,d\omega dx_s dy_s,$$

where $\hat{Q}(x_r, y_r; x_s, y_s; \omega)$ is the acquired seismic data indexed by shot and receiver locations, ω is the frequency, k_x and k_y are wavenumbers in X and Y, respectively, and $e^{i\,\mathrm{sgn}(\omega)(k_x x_s + k_y y_s)}e^{i\omega t}$ is the phase encoding function in the frequency domain.

14. The computing device of Claim 9, further comprising:

rendering the image of said subsurface area according to the following equation

$$R(\vec{x}) = \sum_{k_x,k_y} \int p_B(\vec{x};k_x,k_y;t)\, p_F(\vec{x};k_x,k_y;t)dt$$

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where R is the reflectivity of an interface in the subsurface area, k_x and k_y are wavenumbers on X and Y axes, p_b is backward wavefield, p_f is the forward wavefield, x is a spatial position and t is a corresponding time.

15. A computer readable medium including computer executable instructions, wherein the instructions, when executed, implement a method for processing seismic traces to produce an image of a subsurface area, said method comprising:

receiving a series of seismic traces related to the subsurface area and recorded by one or more seismic receivers, wherein the ~~one or more~~series of seismic ~~sources~~ traces are originally generated by a source;

applying a 3-dimensional (3D) phase encoding function to the series of seismic traces, at least a portion of said seismic traces comprise signals reflected by geological interfaces of the subsurface area;

~~applying a 3-dimensional (3D) harmonic-source reverse time migration of the series of seismic traces encoded with the phase encoding function;~~

computing a forward wavefield by solving a first wave equation that is modified to include the phase encoding function;

computing a backward wavefield by solving a second wave equation that is modified by a 3D harmonic-source reverse time migration of the series of seismic traces encoded with the phase encoding function; and

cross-correlating the forward wavefield with the backward wavefield to generate an image of the subsurface.