

CLAIMS

1. Method of processing marine seismic data gathered by means of at least one seismic streamer towed by a vessel and comprising a plurality of seismic receivers $(R_1, \dots, R_N)$ located at respective water depths $(z_1, \dots, z_N)$, characterized ~~in that it comprises the method comprising~~ an adapted mirror migration step for said data, wherein the recordings of the different seismic receivers $(R_1, \dots, R_N)$ at their effective positions are added to the migration whilst adding the opposite of the same recordings at their mirror positions.

2. Method according to the preceding claim, wherein:

- the calculation of an up-travelling wave is started at an altitude $-Z_{\max}$, $Z_{\max}$ being the maximum depth of the seismic receivers,

- a reverse propagation of the up-travelling wave is made from the initial altitude by a depth recursive calculation in which the up-travelling wave is calculated at a current depth $z+\Delta z$ from the up-travelling wave for the preceding depth z ;

- the receivers whose depth z_r or mirror depth $-z_r$ lies between z and $z+\Delta z$ are added during the calculation.

3. Method according to either of claims 1 and 2, further comprising a propagation step of the down-travelling waves emitted by the source, wherein migration is started at a migration depth equal to the depth of the seismic source z_s , and propagation of the down-travelling waves is carried out to obtain down-

travelling waves for all depths greater than the depth of the source z_s .

4. Method according to claim 3, further comprising a correlation step between the propagated down-travelling wave and the retro-propagated up-travelling wave, for each depth greater than the depth of the source z_s .

5. The method according to one of claims 1 to 4, wherein the adapted mirror migration step comprises:

- recursively calculating an incident wave D emitted by a seismic source at every depth $n\Delta z$ by calculating the incident wave at depth $z+\Delta z$ from the incident wave at depth z , the incident wave being initialized at the depth of the seismic source z_s ,

- recursively calculating a reflected wave U by calculating an up-travelling wave U at depth $z+\Delta z$ from an up-travelling wave at depth z , with the data recorded by the seismic receivers,

- calculating an image of a subsurface by time cross-correlation of the two waves D (x,y,z,t) and U (x,y,z,t) ,

wherein the step of recursively calculating the reflected wave U comprises:

- initializing a reflected wave U assumed to be up-travelling with altimetry migration at an altitude $z_{\max}$, $z_{\max}$ being the maximum depth of the seismic receivers and altitude 0 corresponding to the water surface,

- during a recursive downward movement at z of the wave U between values $-z_{\max}$ and 0, adding recording of a receiver with a sign change at a mirror position $(x_r, y_r, -z_r)$ of the receiver relative to the seafloor, and

- continuing downwards for $z=0$ to $z_{\max}$, adding a recording of the receiver at its real position (x_r, y_r, z_r) .

6. The method according to one of claims 1 to 5, which does not involve a datumning step, datumning being a processing method in which, using data from N seismic receivers of positions (x_n, z_n) where $n=1, \dots, N$, a synthesis is made of data that would have been recorded by the seismic receivers if they had been place at the same horizontal positions x_n but at one same constant reference depth z_0 for all the seismic receivers.

7. The method according to any one of claims 1 to 6, wherein the seismic data are related to a subsurface of a body of water, the further comprising generating and displaying a final image of the subsurface on a display.

8. The method according to claim 7, wherein a one-way wave equation is used to calculate the final image.

9. The method according to claim 7 when dependent on claim 5, wherein the incident wave D is a down-traveling wave traveling from the seismic source to the subsurface, and the reflected wave U is an up-traveling wave traveling from reflectors in the subsurface to the seismic receivers.

5. A method for processing seismic data related to a subsurface of a body of water and displaying a final image of the subsurface on a display, the method comprising:

inputting data indicative of recordings made by detectors disposed on a variable-depth profile in response to an acoustic wave reflected from the subsurface;

applying a matched mirror migration procedure to the data, wherein (i) actual positions of the detectors disposed on the variable-depth profile and corresponding recordings, and (ii) fictitious mirror positions of the actual detectors on the variable-depth profile and corresponding recordings with a changed sign are added in the matched mirror migration; and

generating the final image of the subsurface based on the matched mirror migration procedure.

6. The method of Claim 5, wherein the (i) actual positions of the detectors on the variable-depth profile and corresponding recordings, and the (ii) fictitious mirror positions of the actual detectors on the variable-depth profile and corresponding recordings with a changed sign are applied to an up-traveling U wave that travels from reflectors in the subsurface to the detectors.

7. The method of Claim 5, further comprising:
calculating an up-travelling U wave and a down-travelling wave D; and
time cross-correlating the U wave with the D wave to generate the final image of the subsurface,

wherein the U wave travels from reflectors in the subsurface to the detectors and the D wave travels from a sound source to the subsurface.

8. The method of Claim 7, wherein only the step of calculating the up-travelling U wave is based on both (i) the actual positions of the detectors on the variable-depth profile and the corresponding recordings, and (ii) the fictitious mirror positions of the actual detectors on the variable-depth profile and the corresponding recordings with a changed sign.

9. The method of Claim 8, wherein the step of calculating the down-travelling D wave does not take into consideration the fictitious mirror positions of the actual detectors and the corresponding recordings with a changed sign.

10. The method of Claim 8, wherein the U wave and the D wave are calculated regressively based on a wave equation.

11. The method of Claim 5, wherein a one-way wave equation is used to calculate the final image.

12. The method of Claim 5, wherein no image from a migration step is added to the final image of the matched mirror migration.

13. The method of Claim 5, wherein a step of datuming is not performed prior to calculating the final image, wherein datuming implies using data from the detectors provided at positions (x_n, z_n) , where $n=1, \dots, N$ and N is a natural number,

and synthesizing data that would have been recorded by the detectors if they had been placed at the same horizontal positions x_n but at a same constant reference depth z_0 for all the detectors.

14. The method of Claim 5, wherein the data are collected from detectors being towed by a vessel and the detectors are submerged in water and distributed on the variable-depth profile underwater.

15. The method of Claim 5, further comprising:

calculating an up-travelling U wave from an initial altitude $-z_{\max}$, where $z_{\max}$ is a maximum depth of the detectors;

reverse propagating the up-travelling U wave from the initial altitude by a depth recursive calculation in which the up-travelling U wave is calculated at a current depth $z+\Delta z$ from an up-travelling wave for a preceding depth z ; and

adding the detectors having a depth z_r or a mirror depth $-z_r$ at a current $z+\Delta z$ position of the up-travelling U wave when the detectors lie between z and $z+\Delta z$.

16. The method of Claim 15, further comprising:

propagating a down-travelling D wave emitted by a source of the acoustic wave, wherein the propagation is started at a depth equal to a depth of the source z_s , and the propagation of the down-travelling D wave is carried out to obtain down-travelling waves for all depths greater than the depth of the source z_s .

17. The method of Claim 16, further comprising:

correlating the down-travelling D wave and the up-travelling U wave for each depth greater than the depth of the source z_s .

18. The method of Claim 5, further comprising:

applying a time migration procedure for the matched mirror migration procedure; and

using free-surface boundary conditions for a surface of the water instead of the absorbing boundary conditions, wherein the absorbing boundary conditions assume that a wave is reflected at the surface of the water while the free-surface boundary conditions assume that the wave moves from water into air at the surface of the water.

19. A method for processing seismic data related to a subsurface of a body of water and displaying a final image of the subsurface on a display, the method comprising:

inputting data indicative of recordings made by detectors provided on a variable-depth profile in response to an acoustic wave reflected from the subsurface;

applying a reverse time migration procedure for calculating a final image of the subsurface, wherein the reverse time migration procedures solves the full acoustic wave equation; and

using free-surface boundary conditions for a surface of the water instead of absorbing boundary conditions to calculate the final image, wherein the absorbing boundary conditions assume that a wave is reflected at the surface of the water

while the free-surface boundary conditions assume that the wave moves from the water into air at the surface of the water.

20. The method of Claim 19, wherein the reverse time migration procedure does not use up-traveling and down-traveling waves.

21. The method of Claim 19, wherein the data is collected from detectors being towed by a vessel and the detectors are submerged in water and distributed on the variable-depth profile underwater.

22. An apparatus for processing seismic data related to a subsurface of a body of water, the apparatus comprising:

a processor programmed to perform the following method steps:

receiving data indicative of recordings made by detectors provided on a variable-depth profile in response to an acoustic wave reflected from the subsurface;

applying a matched mirror migration procedure to the data, wherein (i) actual positions of the detectors on the variable-depth profile and corresponding recordings, and (ii) fictitious mirror positions of the actual detectors on the variable-depth profile and corresponding recordings with a changed sign are added in the matched mirror migration; and

generating a final image of the subsurface based on the matched mirror migration procedure.

23. A program storage device, readable by a computer, tangibly embodying a program of instructions executable by the computer for processing seismic data related to a subsurface of a body of water, the instructions comprising:

inputting data indicative of recordings made by detectors provided on a variable-depth profile in response to an acoustic wave reflected from the subsurface;

applying a matched mirror migration procedure to the data, wherein (i) actual positions of the detectors on the variable-depth profile and corresponding recordings, and (ii) fictitious mirror positions of the actual detectors on the variable-depth profile and corresponding recordings with a changed sign are added in the matched mirror migration; and

generating a final image of the subsurface based on the matched mirror migration procedure.

24. A method for generating a final image of a subsurface of a body of water and for displaying the final image on a display, the method comprising:

inputting recordings of plural detectors on a variable-depth profile in response to an acoustic wave reflected from the subsurface;

applying a matched mirror migration procedure to the recordings, wherein (i) actual positions of the detectors on the variable-depth profile and corresponding recordings, and (ii) fictitious mirror positions of the detectors on the variable-depth profile and corresponding recordings with a changed sign are added in the matched mirror migration procedure; and

generating the final image of the subsurface based on the matched mirror migration procedure.