

Claims

What is claimed is:

5 1. A method for estimation of water properties from seismic data, comprising:

 receiving, by a machine, a first seismic data set measured by a plurality of seismic receivers having three-dimensional (3D) coordinates and based on an operation of a plurality of seismic sources having 3D coordinates, wherein the received first
10 seismic data set is indicative of a subterranean formation;

 processing, by the machine, a received first seismic data set comprising at least one event, wherein the processing comprises:

 determining, by the machine, a number of travel times for the at least one event based, at least in part, on the 3D coordinates of the plurality of seismic sources, the 3D coordinates of the plurality of seismic receivers, and water
15 velocity;

 determining, by the machine, an alignment of data values for each of the number of travel times determined for the at least one event;

 compensating for time differences for detection of the at least one event resulting from increasing distance of the plurality of seismic receivers based on the alignment such that the at least one event appears to be detected by the plurality of the seismic sources at the same time;

 determining, by the machine, an estimation of a plurality of undetermined water property values based, at least in part, on the alignment of the data values for each of the number of travel times producing a high
25 quantitative measure of a coherence value and the time compensation, wherein the coherence value is determined based on a number of coefficient values;

 generating a seismic image based on and incorporating the estimation of the plurality of undetermined water property values that is better indicative of the
30 subterranean formation that the received first seismic data set; and

a tangible machine-readable medium storing the seismic image.

2. The method of claim 1, comprising determining a stacking of the data values for each of the number of travel times determined for the at least one event
5 following alignment thereof.

3. The method of claim 2, wherein producing the high quantitative measure of the coherence value comprises producing a high semblance value.

10 4. The method of claim 1, wherein determining the estimation of the plurality of undetermined water property values comprises determining a source height and determining a water velocity.

5. The method of claim 1, wherein determining the number of travel times
15 for the at least one event comprises determining a time between actuation of a seismic source and detection of a resultant wavefield by at least one seismic receiver.

6. The method of claim 5, comprising predefining, in three dimensions, relative positions, at least in part, of a combination of at least two of the seismic source,
20 the at least one seismic receiver, and at least one seismic reflector for each combination thereof.

7. The method of claim 1, comprising:
processing a second seismic data set comprising at least one event, received at a
25 different time than the received first seismic data set, by iterating the elements of claim 1;

comparing estimations of at least one of the plurality of undetermined water property values determined from the received first and second seismic data sets; and
adjusting a value of the estimate of the at least one of the plurality of
30 undetermined water property values based on the comparison.

8. The method of claim 1, wherein the at least one event in the first seismic data set comprises a direct arrival.

5 9. The method of claim 1, wherein the at least one event in the first seismic data set comprises a first order water bottom multiple.

10. The method of claim 1, wherein the at least one event in the first seismic data set comprises a primary water bottom reflection.

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11. The method of claim 1, wherein the at least one event in the first seismic data set comprises a combination of at least two of a direct arrival, a first order water bottom multiple, and a primary water bottom reflection.

15 12. A system for estimation of water properties from seismic data, comprising:

a data store to store seismic data measured by a plurality of seismic receivers having three-dimensional (3D) coordinates and based on an operation of a plurality of seismic sources having 3D coordinates, wherein the stored seismic data is indicative of a subterranean formation;

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a travel time engine comprising hardware to calculate, based on, at least in part, the stored seismic data, the 3D coordinates of the plurality of seismic sources, the 3D coordinates of the plurality of seismic receivers, and water velocity, a number of travel times for at least one wavefield;

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an alignment engine comprising hardware to:

align data values for each of the number of travel times determined for the at least one wavefield as measured by the plurality of seismic receivers; and

compensate for time differences for detection of at least one event resulting from increasing distance of the plurality of seismic receivers based on

the alignment such that the at least one event appears to be detected by the plurality of the seismic sources at the same time;

an estimation engine comprising hardware to:

5 estimate a plurality of undetermined water property values based, at least in part, on the alignment of the data values for each of the number of travel times producing a high semblance value and the compensation;

 generate a seismic image based on and incorporating the estimation of the plurality of undetermined water property values that is better indicative of the subterranean formation that the stored seismic data; and

10 store the seismic image in a tangible machine-readable medium.

13. The system of claim 12, wherein the alignment engine executes:
horizontal alignment of the data values for each of the number of travel times selected from either a direct arrival or a primary water bottom reflection as measured by
15 the plurality of seismic receivers to produce a first matrix and a separate horizontal alignment of a first order water bottom multiple as measured by the plurality of seismic receivers to produce a second matrix.

14. The system of claim 13, wherein the alignment engine executes
20 subtraction of data values of the second matrix from corresponding data values of the first matrix to produce a third matrix.

15. The system of claim 13, wherein the alignment engine executes
multiplication of data values of the second matrix by corresponding data values of the
25 first matrix to produce a third matrix.

16. The system of claim 13, wherein the alignment engine executes
determination of the horizontally aligned data values to comprise compensation for polarity flips to produce the third matrix.

17. The system of claim 13, wherein the alignment engine executes determination of the horizontally aligned data values to comprise an estimated wavelet to produce the third matrix.

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18. The system of claim 13, comprising a stack engine to horizontally stack data values representative of the aligned measurements of the plurality of seismic receivers.

10 19. The system of claim 18, wherein the estimation engine estimates the plurality of undetermined water property values based, at least in part, on the horizontally stacked data values producing the high semblance value.

20. A non-transitory machine-readable medium storing instructions
15 executable by a processing resource to cause a machine to:

receive two sets of three-dimensional (3D) seismic data acquired at different times and measured by a plurality of seismic receivers having 3D coordinates and based on an operation of a plurality of seismic sources having 3D coordinates, wherein the received first seismic data set is indicative of a subterranean formation, and wherein the
20 two sets of 3D seismic data form four-dimensional (4D) seismic data;

calculate travel times of events in the 4D seismic data based, at least in part, on the 3D coordinates of the plurality of seismic sources, the 3D coordinates of the plurality of seismic receivers, and water velocity associated with the 4D seismic data;

align the events based on the calculated travel times for each of the different
25 times;

compensate for time differences for detection of the events resulting from increasing distance of the plurality of seismic receivers based on the alignment such that the events appear to be detected by the plurality of the seismic sources at the same time;

stack the aligned events for each of the different times;

compute a semblance representation for two water properties based on the aligned and stacked events for each of the different times and the compensation;

determine an estimation of two water property values associated with the 4D seismic data based on computed semblance values for each of the different times;

5 generate a seismic image based on and incorporating the estimation of the two water property values that is better indicative of the subterranean formation than the received first seismic data set; and

store the seismic image.

10 21. The medium of claim 20, wherein the instructions executable to calculate the travel times of the events comprise instructions to apply at least one of different weights to events measured at different distances from a seismic source and different phase rotations to events measured at different angles relative to the seismic source.

15 22. The medium of claim 20, comprising instructions to analyze the estimation of the two water property values for each of the different times to detect a change in configuration of a seismic reflector.

20 23. A method of generating a geophysical data product, the method comprising:

obtaining geophysical data from a seismic survey and measured by a plurality of seismic receivers having three-dimensional (3D) coordinates and based on an operation of a plurality of seismic sources having 3D coordinates, wherein the geophysical data is indicative of a subterranean formation;

25 processing the geophysical data to generate the geophysical data product, wherein processing the geophysical data comprises:

determining a number of travel times for the at least one event based, at least in part, on the 3D coordinates of the plurality of seismic sources, the 3D coordinates of the plurality of seismic receivers, and water velocity;

determining an alignment of data values for each of the number of travel times determined for the at least one event;

5 compensating for time differences for detection of the at least one event resulting from increasing distance of the plurality of seismic receivers based on the alignment such that the at least one event appears to be detected by the plurality of the seismic sources at the same time;

10 determining an estimation of a plurality of undetermined water property values based, at least in part, on the alignment of the data values for each of the number of travel times producing a high quantitative measure of a coherence value and the compensation, wherein the coherence value is determined based on a number of coefficient values;

15 generating a seismic image based on and incorporating the estimation of the plurality of undetermined water property values that is better indicative of the subterranean formation than the obtained geophysical data; and

20 recording the seismic image on a non-transitory machine-readable medium, thereby generating the geophysical data product.

24. The method of claim 23, further comprising recording the geophysical data product on a non-transitory, tangible machine-readable medium suitable for
20 importing onshore.