downward through the Earth, is reflected, and, upon its return, is recorded using one or more receivers disposed on or above the subsurface region of the Earth. The seismic data recorded by the receivers may then be used to create an image or profile of the corresponding subsurface region.

[0005] Over time, as hydrocarbons are being extracted from the subsurface region of the Earth, the location, saturation, and other characteristics of the hydrocarbon reservoir and (e.g., overburden) within the subsurface region may change. As such, it may be useful to determine how the image or map of the subsurface region changes over time, such that the operations related to extracting the hydrocarbons may be modified to more efficiently extract the hydrocarbons from the subsurface region of the Earth.

SUMMARY

[0006] A summary of certain embodiments disclosed herein is set forth below. It should be understood that these aspects are presented merely to provide the reader with a brief summary of these certain embodiments and that these aspects are not intended to limit the scope of this disclosure. Indeed, this disclosure may encompass a variety of aspects that may not be set forth below.

[0006a] According to a first aspect of the present invention, there is provided a method for aligning a plurality of seismic images associated with a subsurface region of the Earth, including: receiving, via a processor, the plurality of seismic images acquired via one or more seismic surveys, wherein the plurality of seismic images represents the subsurface region of the Earth; determining, via the processor, a first respective relative shift volume between a first seismic image of the plurality of seismic images and a second seismic image of the plurality of seismic images, a second respective relative shift volume between the first seismic image and a third seismic image of the plurality of seismic images, and a third respective relative shift volume between the second seismic image of the plurality of seismic images and the third seismic image of the plurality of seismic images; determining a first shift volume associated with the first

seismic image and a second shift volume associated with the second seismic image based on the first, second, and third respective relative shift volumes, wherein the first shift volume indicates position differences in space between seismic events; and applying, via the processor, the first shift volume to the first seismic image and the second shift volume to the second seismic image to generate a first shifted seismic image and a second shifted seismic image, respectively, wherein the first and second shifted seismic images are aligned with each other and indicate one or more properties of hydrocarbon deposits within the subsurface region of the Earth.

[0006b] According to a second aspect of the present invention, there is provided a non-transitory computer-readable medium, including computer-executable instructions configured to cause a processor to: (a) receive a plurality of seismic images acquired via a plurality of seismic sensors, wherein the plurality of seismic images represents a subsurface region of the Earth; (b) receive a number K of index images; (c) assign one of the plurality of seismic images as a pilot image; (d) determine a first respective relative shift volume between the pilot image and each seismic image of the plurality of seismic images within the number K of index images to the pilot image; (e) repeat blocks (c) and (d) for each remaining seismic image of the plurality of seismic images as the pilot image, thereby determining a plurality of relative shift volumes; (f) determine N number of shift volumes based on the plurality of relative shift volumes, wherein the N number corresponds to a number of the plurality of seismic images received, and wherein each respective shift volume of the N number of shift volumes corresponds to a respective seismic image of the plurality of seismic images, and at least one shift volume indicates position differences in space between seismic events; and (g) apply each respective shift volume of the N number of shift volumes to the respective seismic image of the plurality of seismic images, thereby generating a plurality of shifted seismic images, wherein each of the plurality of shifted seismic images are aligned with each other and indicate one or more properties of hydrocarbon deposits within the subsurface region of the Earth.

[0006c] According to a third aspect of the present invention, there is provided a method for drilling into a subsurface region of the Earth, including: analyzing a plurality of shifted seismic images associated with the subsurface region, wherein each of the plurality of shifted seismic images is aligned with each other; and performing one or more drilling operations or one or more

production operations into the subsurface region based on an analysis of the plurality of shifted seismic images, wherein the plurality of shifted seismic images is determined by: receiving, via a processor, a plurality of seismic images acquired in one or more seismic surveys, wherein the plurality of seismic images represents the subsurface region of the Earth; determining, via the processor, a first respective relative shift volume between a first seismic image of the plurality of seismic images and a second seismic image of the plurality of seismic images, a second respective relative shift volume between the first seismic image and a third seismic image of the plurality of seismic images, and a third respective relative shift volume between the second seismic image of the plurality of seismic images and the third seismic image of the plurality of seismic images; determining a first shift volume associated with the first seismic image and a second shift volume associated with the second seismic image based on the first, second, and third respective relative shift volumes, wherein the first shift volume indicates position differences in space between seismic events; and applying, via the processor, the first shift volume to the first seismic image and the second shift volume to the second seismic image to generate a first shifted seismic image and a second shifted seismic image, respectively, of the plurality of shifted seismic images.

[0006d] According to a fourth aspect of the present invention, there is provided a method for aligning a plurality of seismic images associated with a subsurface region of the Earth, including: receiving, via a processor, the plurality of seismic images acquired via one or more seismic surveys, wherein the plurality of seismic images represents the subsurface region of the Earth; determining, via the processor, a first respective relative shift volume between a first seismic image of the plurality of seismic images and a second seismic image of the plurality of seismic images, a second respective relative shift volume between the first seismic image and a third seismic image of the plurality of seismic images, and a third respective relative shift volume between the second seismic image of the plurality of seismic images and the third seismic image of the plurality of seismic images; determining a first shift volume associated with the first seismic image and a second shift volume associated with the second seismic image based on the first, second, and third respective relative shift volumes, wherein the first shift volume indicates position differences in space between seismic events; and applying, via the processor, the first shift volume to the first seismic image and the second shift volume to the second seismic image

to generate a first shifted seismic image and a second shifted seismic image, respectively, wherein the first and second shifted seismic images are aligned with each other and indicate one or more properties of hydrocarbon deposits within the subsurface region of the Earth.

[0006e] According to a fifth aspect of the present invention, there is provided a non-transitory computer-readable medium, including computer-executable instructions configured to cause a processor to: (a) receive a plurality of seismic images acquired via a plurality of seismic sensors, wherein the plurality of seismic images represents a subsurface region of the Earth; (b) receive a number K of index images; (c) assign one of the plurality of seismic images as a pilot image; (d) determine a first respective relative shift volume between the pilot image and each seismic image of the plurality of seismic images within the number K of index images to the pilot image; (e) repeat blocks (c) and (d) for each remaining seismic image of the plurality of seismic images as the pilot image, thereby determining a plurality of relative shift volumes; (f) determine N number of shift volumes based on the plurality of relative shift volumes, wherein the N number corresponds to a number of the plurality of seismic images received, and wherein each respective shift volume of the N number of shift volumes corresponds to a respective seismic image of the plurality of seismic images, and at least one shift volume indicates position differences in space between seismic events; and (g) apply each respective shift volume of the N number of shift volumes to the respective seismic image of the plurality of seismic images, thereby generating a plurality of shifted seismic images, wherein each of the plurality of shifted seismic images are aligned with each other and indicate one or more properties of hydrocarbon deposits within the subsurface region of the Earth.

[0007] Seismic data processing, such as seismic data registration, may involve determining a multi-dimensional displacement volume (which may be a shift solution indicative of position differences between corresponding events in two seismic images or datasets). Generally, the two seismic images may be acquired at two different times, but it should be noted that the seismic data registration techniques may also be performed using two seismic images acquired at the same time in order to align them (or to resolve

CLAIMS

1. A method for aligning a plurality of seismic images associated with a subsurface region of the Earth, comprising:

receiving, via a processor, the plurality of seismic images acquired via one or more seismic surveys, wherein the plurality of seismic images represents the subsurface region of the Earth;

determining, via the processor, a first respective relative shift volume between a first seismic image of the plurality of seismic images and a second seismic image of the plurality of seismic images, a second respective relative shift volume between the first seismic image and a third seismic image of the plurality of seismic images, and a third respective relative shift volume between the second seismic image of the plurality of seismic images and the third seismic image of the plurality of seismic images;

determining a first shift volume associated with the first seismic image and a second shift volume associated with the second seismic image based on the first, second, and third respective relative shift volumes, wherein the first shift volume indicates position differences in space between seismic events; and

applying, via the processor, the first shift volume to the first seismic image and the second shift volume to the second seismic image to generate a first shifted seismic image and a second shifted seismic image, respectively, wherein the first and second shifted seismic images are aligned with each other and indicate one or more properties of hydrocarbon deposits within the subsurface region of the Earth.

2. The method of claim 1, wherein determining the first respective relative shift volume comprises:

generating, via the processor, a first scaled image based on the first seismic image and a second scaled image based on the second seismic image;

determining, via the processor, a scaled displacement volume between the first scaled image and the second scaled image based on an optical flow algorithm; and

determining, via the processor, a displacement volume based on the scaled displacement volume and a scaling function used to generate the first and second scaled images based on the first and second seismic images.

3. The method of claim 1, wherein determining the first respective relative shift volume comprises:

(a) receiving a number of iterations M;

(b) obtaining, via the processor, the displacement volume at a current scale using an optical flow algorithm or the scaled displacement volume from a previous scale;

(c) applying, via the processor, the displacement volume to the second seismic image thereby generating a third image;

(d) determining, via the processor, a second displacement volume between the first seismic image and the third image;

(e) updating, via the processor, the displacement volume by adding the second displacement volume to the displacement volume;

(f) iteratively repeating blocks (c) - (e) *M*-1 times by using a respective second displacement volume and a respective third image each time, thereby determining an M-number displacement volume; and

(g) assigning the M-number displacement volume as the displacement volume.

4. The method of claim 2, wherein the optical flow algorithm comprises a multi-dimensional Horn-Schunck algorithm or a multi-dimensional Lucas-Kanade algorithm.

5. The method of claim 1, wherein determining the first shift volume, and the second shift volume comprises applying a least squares method to a linear equation system comprising the first, second, and third respective relative shift volumes.

6. The method of claim 1, comprising deriving, via the processor, a plurality of errors associated with the first seismic image and the second seismic image based on the first, second, and third respective relative shift volumes.

7. The method of claim 1, comprising displaying the first shifted seismic image and the second shifted seismic image on a display or other tangible element.

8. The method of claim 1, wherein determining the first respective relative shift volume comprises:

receiving, via the processor, a number K of index images; and

determining, via the processor, a respective first relative shift volume between the first seismic image and each respective seismic image of the plurality of seismic images positioned within the number K of index images away, wherein the number K of index images associated with the first seismic image is based on a second number of images indexed after the first seismic image with respect to the plurality of seismic images.

9. A non-transitory computer-readable medium, comprising computer-executable instructions configured to cause a processor to:

(a) receive a plurality of seismic images acquired via a plurality of seismic sensors, wherein the plurality of seismic images represents a subsurface region of the Earth;

(b) receive a number K of index images;

(c) assign one of the plurality of seismic images as a pilot image;

(d) determine a first respective relative shift volume between the pilot image and each seismic image of the plurality of seismic images within the number K of index images to the pilot image;

(e) repeat blocks (c) and (d) for each remaining seismic image of the plurality of seismic images as the pilot image, thereby determining a plurality of relative shift volumes;

(f) determine N number of shift volumes based on the plurality of relative shift volumes, wherein the N number corresponds to a number of the plurality of seismic images received, and wherein each respective shift volume of the N number of shift volumes corresponds to a respective seismic image of the plurality of seismic images, and at least one shift volume indicates position differences in space between seismic events; and

(g) apply each respective shift volume of the N number of shift volumes to the respective seismic image of the plurality of seismic images, thereby generating a plurality of shifted seismic images, wherein each of the plurality of shifted seismic images are aligned with each other and indicate one or more properties of hydrocarbon deposits within the subsurface region of the Earth.

10. The non-transitory computer-readable medium of claim 9, wherein the number K of index images is received via user input.

11. The non-transitory computer-readable medium of claim 9, wherein the first respective relative shift volume comprises a volume of shift scalars or vectors.

12. The non-transitory computer-readable medium of claim 9, wherein the computer-executable instructions cause the processor to determine amplitude properties, velocity properties, rock type properties, or any combination thereof regarding one or more geological layers within the subsurface region of the Earth based on the plurality of shifted seismic images.

13. The non-transitory computer-readable medium of claim 9, wherein a number of seismic images within the number K of index images to the pilot image is different for two pilot seismic images of the plurality of seismic images.

14. The non-transitory computer-readable medium of claim 9, wherein the first respective relative shift volume is determined using an iterative refinement approach or/and a multi-scale approach and an optical flow algorithm.

15. The non-transitory computer-readable medium of claim 14, wherein the computer-executable instructions are configured to cause the plurality of shifted seismic images to be printed or displayed.

16. A method for drilling into a subsurface region of the Earth, comprising:

analyzing a plurality of shifted seismic images associated with the subsurface region, wherein each of the plurality of shifted seismic images is aligned with each other; and

performing one or more drilling operations or one or more production operations into the subsurface region based on an analysis of the plurality of shifted seismic images, wherein the plurality of shifted seismic images is determined by:

receiving, via a processor, a plurality of seismic images acquired in one or more seismic surveys, wherein the plurality of seismic images represents the subsurface region of the Earth;

determining, via the processor, a first respective relative shift volume between a first seismic image of the plurality of seismic images and a second seismic image of the plurality of seismic images, a second respective relative shift volume between the first seismic image and a third seismic image of the plurality of seismic images, and a third respective relative shift volume between the second seismic image of the plurality of seismic images and the third seismic image of the plurality of seismic images;

determining a first shift volume associated with the first seismic image and a second shift volume associated with the second seismic image based on the first, second, and third respective relative shift volumes, wherein the first shift volume indicates position differences in space between seismic events; and

applying, via the processor, the first shift volume to the first seismic image and the second shift volume to the second seismic image to generate a first shifted seismic image and a second shifted seismic image, respectively, of the plurality of shifted seismic images.

17. The method of claim 16, wherein the first seismic image is associated with a first set of seismic data acquired by a set of seismic receivers during a marine seismic survey or a land seismic survey.

18. The method of claim 17, wherein the second seismic image is associated with a second set of seismic data acquired by the set of seismic receivers based on a same seismic source associated with the first set of seismic data.

19. The method of claim 18, wherein the first shift volume and the second shift volume are determined using a least squares method.

20. The method of claim 16, wherein the first seismic image is associated with a first set of seismic data acquired by a first seismic receiver of a seismic survey, and wherein the second seismic image is associated with a second set of seismic data acquired by a second seismic receiver of the seismic survey.

21. A method (160) for aligning a plurality of seismic images associated with a subsurface region of the Earth, comprising:

receiving (162), via a processor (64), the plurality of seismic images acquired via one or more seismic surveys, wherein the plurality of seismic images represents the subsurface region of the Earth;

determining (168), via the processor (64), a first respective relative shift volume between a first seismic image of the plurality of seismic images and a second seismic image of the plurality of seismic images, a second respective relative shift volume between the first seismic image and a third seismic image of the plurality of seismic images, and a third respective relative shift volume between the second seismic image of the plurality of seismic images and the third seismic image of the plurality of seismic images;

determining (174) a first shift volume associated with the first seismic image and a second shift volume associated with the second seismic image based on the first,

second, and third respective relative shift volumes, wherein the first shift volume indicates position differences in space between seismic events; and

applying (176), via the processor (64), the first shift volume to the first seismic image and the second shift volume to the second seismic image to generate a first shifted seismic image and a second shifted seismic image, respectively, wherein the first and second shifted seismic images are aligned with each other and indicate one or more properties of hydrocarbon deposits within the subsurface region (26) of the Earth.

22. The method of claim 21, wherein determining the first respective relative shift volume comprises:

generating, via the processor (64), a first scaled image based on the first seismic image and a second scaled image based on the second seismic image;

determining, via the processor (64), a scaled displacement volume between the first scaled image and the second scaled image based on an optical flow algorithm; and

determining, via the processor (64), a displacement volume based on the scaled displacement volume and a scaling function used to generate the first and second scaled images based on the first and second seismic images.

23. The method of claim 21, wherein determining the first respective relative shift volume comprises:

(a) receiving a number of iterations M;

(b) obtaining, via the processor (64), the displacement volume at a current scale using an optical flow algorithm or the scaled displacement volume from a previous scale;

(c) applying, via the processor (64), the displacement volume to the second seismic image thereby generating a third image;

(d) determining, via the processor (64), a second displacement volume between the first seismic image and the third image;

(e) updating, via the processor (64), the displacement volume by adding the second displacement volume to the displacement volume;

(f) iteratively repeating blocks (c) - (e) M-1 times by using a respective second displacement volume and a respective third image each time, thereby determining an M-number displacement volume; and

(g) assigning the M-number displacement volume as the displacement volume.

24. The method of claim 22, wherein the optical flow algorithm comprises a multi-dimensional Horn-Schunck algorithm or a multi-dimensional Lucas-Kanade algorithm.

25. The method of claim 21, wherein determining the first shift volume, and the second shift volume comprises applying a least squares method to a linear equation system comprising the first, second, and third respective relative shift volumes.

26. The method of claim 21, comprising deriving, via the processor (64), a plurality of errors associated with the first seismic image and the second seismic image based on the first, second, and third respective relative shift volumes.

27. The method of claim 21, comprising displaying the first shifted seismic image and the second shifted seismic image on a display or other tangible element.

28. The method of claim 21, wherein determining the first respective relative shift volume comprises:

receiving, via the processor (64), a number K of index images; and

determining, via the processor (64), a respective first relative shift volume between the first seismic image and each respective seismic image of the plurality of seismic images positioned within the number K of index images away, wherein the number K of index images associated with the first seismic image is based on a second number of images indexed after the first seismic image with respect to the plurality of seismic images.

29. A non-transitory computer-readable medium (66), comprising computer-executable instructions configured to cause a processor (64) to:

(a) receive (162) a plurality of seismic images acquired via a plurality of seismic sensors, wherein the plurality of seismic images represents a subsurface region of the Earth;

(b) receive (164) a number K of index images;

(c) assign (166) one of the plurality of seismic images as a pilot image;

(d) determine (168) a first respective relative shift volume between the pilot image and each seismic image of the plurality of seismic images within the number K of index images to the pilot image;

(e) repeat (170) blocks (c) and (d) for each remaining seismic image of the plurality of seismic images as the pilot image, thereby determining a plurality of relative shift volumes;

(f) determine (174) N number of shift volumes based on the plurality of relative shift volumes, wherein the N number corresponds to a number of the plurality of seismic images received, and wherein each respective shift volume of the N number of shift volumes corresponds to a respective seismic image of the plurality of seismic images, and at least one shift volume indicates position differences in space between seismic events; and

(g) apply (176) each respective shift volume of the N number of shift volumes to the respective seismic image of the plurality of seismic images, thereby generating a plurality of shifted seismic images, wherein each of the plurality of shifted seismic images are aligned with each other and indicate one or more properties of hydrocarbon deposits within the subsurface region (26) of the Earth.

30. The non-transitory computer-readable medium (66) of claim 29, wherein the number K of index images is received via user input.

31. The non-transitory computer-readable medium (66) of claim 29, wherein the first respective relative shift volume comprises a volume of shift scalars or vectors.

32. The non-transitory computer-readable medium (66) of claim 29, wherein the computer-executable instructions cause the processor (64) to determine amplitude properties, velocity properties, rock type properties, or any combination thereof regarding one or more geological layers within the subsurface region of the Earth based on the plurality of shifted seismic images.

33. The non-transitory computer-readable medium (66) of claim 29, wherein a number of seismic images within the number K of index images to the pilot image is different for two pilot seismic images of the plurality of seismic images.

34. The non-transitory computer-readable medium (66) of claim 29, wherein the first respective relative shift volume is determined using an iterative refinement approach or/and a multi-scale approach and an optical flow algorithm.

35. The non-transitory computer-readable medium (66) of claim 34, wherein the computer-executable instructions are configured to cause the plurality of shifted seismic images to be printed or displayed.