[0005] Seismic survey designs provide locations for the energy sources and receivers (otherwise known as acquisition geometry). The survey designs are generated with a goal of ensuring that seismic acquisition will have adequate illumination of targets of interest to allow for imaging or mapping of the subsurface region. As such, it may be useful to develop survey designs that result in improvements of the imaging or mapping of the subsurface region, 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 first aspect, there is provided a computer-implemented method, including: selecting a plurality of sets of source and receiver locations over a survey area to improve a velocity model of a region of interest, wherein the region of interest corresponds to a problematic region in which use of the velocity model results in poor image quality; performing forward modeling on ~~a subsurface attribute model of a subterranean region~~ the velocity model based on each source and receiver pair of the plurality of sets of source and receiver locations to generate low frequency seismic data; performing a reverse time migration on the low frequency seismic data to reposition refraction wave and/or diving wave energy of each source and receiver pair of the plurality of sets of source and receiver locations to generate a diving wave illumination image; extracting, for each source and receiver pair of the plurality of sets of source and receiver locations, seismic amplitudes from the diving wave illumination image around a region of interest; ~~and~~ computing a contribution of a respective diving wave from each source and receiver pair of the plurality of sets of source and receiver locations to diving waves passing through the region of interest; and designing an acquisition geometry of a survey design based on the computing of the contribution of the respective diving wave from each source and receiver pair of the plurality of sets of source and receiver locations to the diving waves passing through the region of interest.

[0006b] According to a second aspect, there is provided a tangible, non-transitory, machine-readable media, including instructions configured to cause a processor to: select a plurality of sets of source and receiver locations over a survey area to improve a velocity model of a region of interest, wherein the region of interest corresponds to a problematic region in which use of the velocity model results in poor image quality; ~~model~~perform forwarding modeling on ~~a~~the velocity model ~~of a subterranean region~~based on each source and receiver pair of the plurality of sets of source and receiver locations to generate low frequency seismic

data; performing a reverse time migration on the low frequency seismic data to reposition diving wave energy of each source and receiver pair of the plurality of sets of source and receiver locations to generate a diving wave illumination image; extract, for each source and receiver pair of the plurality of sets of source and receiver locations, seismic amplitudes from the diving wave illumination image at a region of interest; compute a contribution of a respective diving wave from each source and receiver pair of the plurality of sets of source and receiver locations to diving waves passing through the region of interest; ~~and~~ calculate results indicative of the contribution of the respective diving wave from each source and receiver pair of the plurality of sets of source and receiver locations to the diving waves passing through the region of interest; and design an acquisition geometry of a survey design based upon the results.

[0006c] According to a third aspect, there is provided a device including: a processor configured to: select a plurality of sets of source and receiver locations over a survey area to improve a velocity model of a region of interest, wherein the region of interest corresponds to a problematic region in which use of the velocity model results in poor image quality; ~~model~~ perform forwarding modeling on the velocity model ~~on a subsurface attribute model of a subterranean region~~based on each source and receiver pair of the plurality of sets of source and receiver locations to generate low frequency seismic data; perform a reverse time migration on the low frequency seismic data to reposition diving wave energy of each source and receiver pair of the plurality of sets of source and receiver locations to generate a diving wave illumination image; extract, for each source and receiver pair of the plurality of sets of source and receiver locations, seismic amplitudes from the diving wave illumination image at a region of interest; ~~and~~ compute a contribution of a respective diving wave from each source and receiver pair of the plurality of sets of source and receiver locations to diving waves passing through the region of interest; and design an acquisition geometry of a survey design based upon the contribution of the respective diving wave from each source and receiver pair of the plurality of sets of source and receiver locations to the diving waves passing through the region of interest.

[0007] Seismic acquisition utilizing sources and receivers may be useful in the generation of, for example, seismic images or velocity models. Seismic images may be used, for example, in the determination of hydrocarbon deposits (e.g., areas within a subsurface that contain hydrocarbons) and/or subsurface drilling hazards. Seismic images are generally produced using seismic waveforms produced by a source, reflected off regions within a subsurface, and received by one or more receivers. The seismic images that are generated depend greatly on the locations of the sources and receivers, also known as the acquisition geometry, of a seismic survey design. Trial and error may be used to determine the acquisition geometry of a seismic survey design. However, seismic surveying is too costly to be performed using trial and error to find a suitable acquisition geometry. So computational modeling and analysis can be used to evaluate prospective acquisition geometries to determine which might yield the most desirable survey results.

CLAIMS

~~What is claimed is:~~

1. A computer-implemented method, comprising:

selecting a plurality of sets of source and receiver locations over a survey area to improve a velocity model of a region of interest, wherein the region of interest corresponds to a problematic region in which use of the velocity model results in poor image quality;

performing forward modeling on ~~a subsurface attribute model of a subterranean region~~the velocity model based on each source and receiver pair of the plurality of sets of source and receiver locations to generate low frequency seismic data;

performing a reverse time migration on the low frequency seismic data to reposition refraction wave and/or diving wave energy of each source and receiver pair of the plurality of sets of source and receiver locations to generate a diving wave illumination image;

extracting, for each source and receiver pair of the plurality of sets of source and receiver locations, seismic amplitudes from the diving wave illumination image around the~~a~~ region of interest; ~~and~~

computing a contribution of a respective diving wave from each source and receiver pair of the plurality of sets of source and receiver locations to diving waves passing through the region of interest; and

designing an acquisition geometry of a survey design based on the computing of the contribution of the respective diving wave from each source and receiver pair of the plurality of sets of source and receiver locations to the diving waves passing through the region of interest.

~~2. The method of claim 1, comprising designing an acquisition geometry of a survey design based upon the computing of the contribution of the respective diving wave from each source and receiver pair of the plurality of sets of source and receiver locations to the diving waves passing through the region of interest.~~

~~3~~2. The computer-implemented method of claim ~~2~~1, comprising generating an updated velocity model utilizing the acquisition geometry of the survey design and a location of the region of interest.

~~4~~3. The computer-implemented method of claim 1, comprising generating a map of seismic acquisition geometry of a survey design indicative of the contribution of the respective diving wave from each source and receiver pair of the plurality of sets of source and receiver locations to the diving waves passing through the region of interest.

~~5~~4. The computer-implemented method of claim ~~4~~3, comprising generating a final acquisition geometry of the survey design based upon the map of seismic acquisition geometry of a survey design.

~~6~~5. The computer-implemented method of claim 1, comprising generating results indicative of the contribution of the respective diving wave from each source and receiver pair of the plurality of sets of source and receiver locations to the diving waves passing through the region of interest.

~~7~~6. The computer-implemented method of claim ~~6~~5, comprising generating a final acquisition geometry of a survey design based upon the results.

~~8. The method of claim 1, wherein the subsurface attribute model comprises a velocity model.~~

~~9~~7. The computer-implemented method of claim 1, wherein the low frequency seismic data comprise frequencies of between approximately 1.0 Hz - 10.0 Hz.

~~10~~8. A tangible, non-transitory, machine-readable media, comprising instructions configured to cause a processor to:

select a plurality of sets of source and receiver locations over a survey area to improve a velocity model of a region of interest, wherein the region of interest corresponds to a problematic region in which use of the velocity model results in poor image quality;

~~model~~ perform forwarding modeling on ~~a~~the velocity model ~~of a subterranean region~~based on each source and receiver pair of the plurality of sets of source and receiver locations to generate low frequency seismic data;

performing a reverse time migration on the low frequency seismic data to reposition diving wave energy of each source and receiver pair of the plurality of sets of source and receiver locations to generate a diving wave illumination image;

extract, for each source and receiver pair of the plurality of sets of source and receiver locations, seismic amplitudes from the diving wave illumination image at thea region of interest;

compute a contribution of a respective diving wave from each source and receiver pair of the plurality of sets of source and receiver locations to diving waves passing through the region of interest; and

calculate results indicative of the contribution of the respective diving wave from each source and receiver pair of the plurality of sets of source and receiver locations to the diving waves passing through the region of interest; and

design an acquisition geometry of a survey design based upon the results.

11. The tangible, non-transitory, machine-readable media of claim 10, comprising instructions configured to cause the processor to design an acquisition geometry of a survey design based upon the results.

129. The tangible, non-transitory, machine-readable media of claim 118, comprising instructions configured to cause the processor to generate an updated velocity model utilizing the acquisition geometry of the survey design and a location of the region of interest.

1310. A device comprising:

a processor configured to:

select a plurality of sets of source and receiver locations over a survey area to improve a velocity model of a region of interest, wherein the region of interest corresponds to a problematic region in which use of the velocity model results in poor image quality;

model perform forwarding modeling on the velocity model on a subsurface attribute model of a subterranean regionbased on each source and receiver pair of the plurality of sets of source and receiver locations to generate low frequency seismic data;

perform a reverse time migration on the low frequency seismic data to reposition diving wave energy of each source and receiver pair of the plurality of sets of source and receiver locations to generate a diving wave illumination image;

extract, for each source and receiver pair of the plurality of sets of source and receiver locations, seismic amplitudes from the diving wave illumination image at ~~a~~the region of interest; ~~and~~

compute a contribution of a respective diving wave from each source and receiver pair of the plurality of sets of source and receiver locations to diving waves passing through the region of interest; and

design an acquisition geometry of a survey design based upon the contribution of the respective diving wave from each source and receiver pair of the plurality of sets of source and receiver locations to the diving waves passing through the region of interest.

~~14. The device of claim 13, wherein the processor is configured to design an acquisition geometry of a survey design based upon the contribution of the respective diving wave from each source and receiver pair of the plurality of sets of source and receiver locations to the diving waves passing through the region of interest.~~

~~15~~11. The device of claim ~~14~~10, wherein the processor is configured to generate an updated velocity model utilizing the acquisition geometry of the survey design and a location of the region of interest.

~~16~~12. The device of claim ~~13~~10, wherein the processor is configured generate a map of seismic acquisition geometry of a survey design indicative of the contribution of the respective diving wave from each source and receiver pair of the plurality of sets of source and receiver locations to the diving waves passing through the region of interest.

~~17~~13. The device of claim ~~16~~12, comprising an output configured to transmit the map of seismic acquisition geometry of a survey design to be used in generating a final acquisition geometry of the survey design.

~~18~~14. The device of claim ~~13~~10, wherein the processor is configured to generate results indicative of the contribution of the respective diving wave from each source and receiver pair of the plurality of sets of source and receiver locations to the diving waves passing through the region of interest.

~~19~~15. The device of claim ~~18~~14, comprising an output configured to transmit the results to be used in generating a final acquisition geometry of a survey design.

~~20. The device of claim 13, wherein the processor is configured to utilize an initial velocity model as the subsurface attribute model comprises a velocity model.~~