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(71) Applicant *(for all designated States except US):* **EXXON¬MOBIL UPSTREAM RESEARCH COMPANY** [US/US]; P.O. Box 2189 (CORP-URC-SW 341), Houston, TX 77252-2189 (US).

(72) Inventors; and

(75) Inventors/Applicants *(for US only):* **KREBS, Jerome, R.** [US/US]; 2006 Hillside Oak, Houston, TX 77062 (US). **ANDERSON, John,** E. [US/US]; 351 1 Fresh Meadow Drive, Houston, TX 77063 (US). **NEELAMANI, Ramesh** [IN/US]; 1010 Bartlett Street, Houston, TX 77006 (US). **JING, Charlie** [US/US]; 2502 Jasmine Ridge Court, Houston, TX 77062 (US). **HINKLEY, David** [US/US]; 1207 Roseberry Manor Drive, Spring, TX 77379 (US). **DICKENS, Thomas,** A. [US/US]; 5454 Newcastle #1903, Houston, TX 77081 (US). **KROHN, Christine,** E. [US/US]; 1827 Nocturne, Houston, TX 77043 (US). **TRAYNIN, Peter** [US/US]; 15106 Windsdowne Lane, Cypress, TX 77429 (US).

(74) Agents: **PLUMMER, J., Paul** et al.; Exxonmobile Upstream Research Company, P.O. Box 2189 (CORP-URC-SW 341), Houston, TX 77252-2189 (US).

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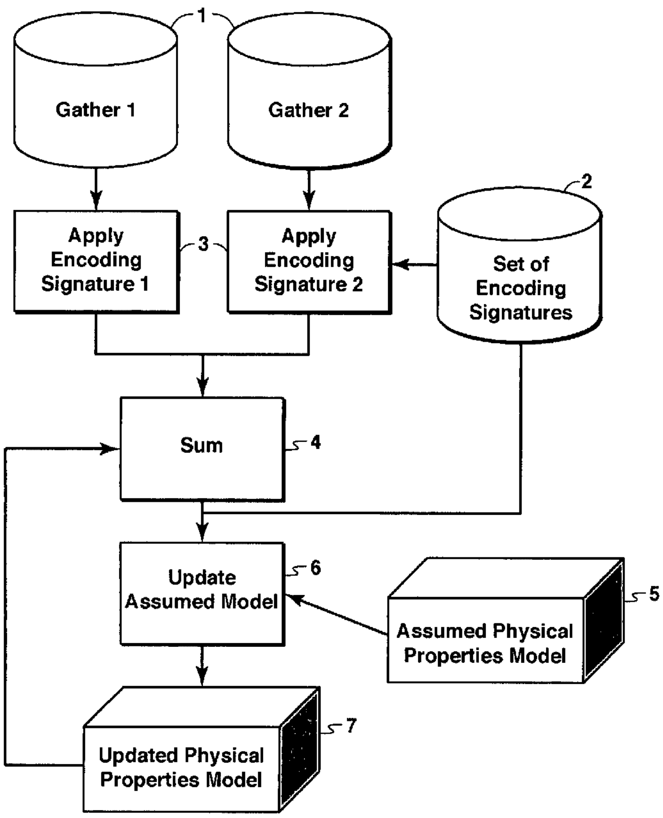
(54) Title: ITERATIVE INVERSION OF DATA FROM SIMULTANEOUS GEOPHYSICAL SOURCES



(57) Abstract: Method for reducing the time needed to perform geophysical inversion by using simultaneous encoded sources in the simulation steps of the inversion process. The geophysical survey data are prepared by encoding (3) a group of source gathers (1), using for each gather a different encoding signature selected from a set (2) of non-equivalent encoding signatures. Then, the encoded gathers are summed (4) by summing all traces corresponding to the same receiver from each gather, resulting in a simultaneous encoded gather. (Alternatively, the geophysical data are acquired from simultaneously encoded sources.) The simulation steps needed for inversion are then calculated using a particular assumed velocity (or other physical property) model (5) and simultaneously activated encoded sources using the same encoding scheme used on the measured data. The result is an updated physical properties model (6) that may be further updated (7) by additional iterations.

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AMENDED CLAIMS
+ STATEMENT
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1. A computer-implemented method for inversion of measured geophysical data to determine a physical properties model for a subsurface region, comprising:

(a) obtaining a group of two or more encoded gathers of the measured geophysical data, wherein each gather is associated with a single generalized source or, using source-receiver reciprocity, with a single receiver, and wherein each gather is encoded with a different encoding signature selected from a set non-equivalent encoding signatures;

(b) summing the encoded gathers in the group by summing all data records in each gather that correspond to a single receiver (or source if reciprocity is used), and repeating for each different receiver, resulting in a simultaneous encoded gather;

(c) assuming a physical properties model of the subsurface region, said model providing values of at least one physical property at locations throughout the subsurface region;

(d) calculating an update to the assumed physical properties model that is more consistent with the simultaneous encoded gather from step (b), said calculation involving one or more encoded simultaneous source forward (or reverse) simulation operations that use the assumed physical properties model and encoded source signatures using the same encoding functions used to encode corresponding gathers of measured data, wherein an entire simultaneous encoded gather is simulated in a single simulation operation;

(e) repeating step (d) at least one more iteration, using the updated physical properties model from the previous iteration of step (d) as the assumed model to produce a further updated physical properties model of the subsurface region that is more consistent with a corresponding simultaneous encoded gather of measured data, using the same encoding signatures for source signatures in the simulation as were used in forming the corresponding simultaneous encoded gather of measured data; and

(f) downloading the further updated physical properties model or saving it to computer storage.

2. The method of claim 1, wherein a cost function is optimized to update the model in step (d), said cost function measuring degree of misfit between the simultaneous encoded gather and a simulated simultaneous encoded gather.

3. The method of claim 1, further comprising after step (d) and before step (e): changing the encoding signatures assigned in step (a) and repeating step (b) to obtain a different simultaneous encoded gather of measured data, then using that in performing step (e).

4. The method of claim 1, further comprising obtaining at least one additional group of two or more encoded gathers of the measured geophysical data as in step (a), and performing step (b) for each additional group, then accumulating the corresponding updates to the physical properties model from step (d), wherein the updated physical properties model to be used in step (e) is based on the accumulated updates.

5. The method of claim 1, wherein said encoded gathers of measured data are encoded by temporally convolving all traces from the gather with the encoding signature selected for the gather.

6. The method of claim 1, wherein the two or more encoded gathers of measured data are obtained by obtaining gathers of data from a geophysical survey in which data are acquired from a plurality of simultaneously operating, uniquely encoded source devices.

7. The method of claim 1, wherein the measured geophysical data are from a seismic survey.

8. The method of claim 7, wherein the generalized seismic sources are either all point sources or all plane-wave sources.

9. The method of claim 5, wherein the measured geophysical data include measured or estimated signatures of each source activation and the encoded source signatures used in the simulation operations are signatures made by temporally convolving the measured or estimated source signatures with the same encoding functions used to encode the corresponding measured gather in step (a).

10. The method of claim 5, wherein the encoding functions are of a type selected from a group consisting of linear, random phase, chirp, modified chirp, random time shift, and frequency independent phase encoding.

11. The method of claim 5, wherein the encoding functions are of one type for some sources and of another type for other sources.

12. The method of claim 2, wherein the encoding functions are optimized to improve quality of the selected cost function.

13. The method of claim 1, wherein the forward or reverse simulation operations in step (d) are performed with a finite difference, finite element or finite volume simulation code.

14. The method of claim 7, wherein the physical properties models are models of seismic wave velocity, seismic elastic parameters, seismic anisotropy parameters or seismic anelasticiry parameters.

15. The method of claim 2, wherein a global cost function optimization method such as Monte Carlo, simulated annealing, genetic or evolution algorithm is used to update the model.

16. The method of claim 2, wherein a local cost function optimization method such as gradient line search, conjugate gradients or Newton's method is used to update the model.

17. The method of claim 2, wherein the cost function is the Ll-norm cost function or the L2-norm cost function and the cost function may contain regularization terms.

18. The method of claim 1, wherein step (d) is performed by:

(i) selecting an iterative series solution to a scattering equation describing wave scattering in said subsurface region;

(ii) beginning with the first n terms of said series, where $n \geq 1$, said first n terms corresponding to the assumed physical properties model of the subsurface region;

(iii) computing the next term in the series, said calculation involving one or more encoded simultaneous source forward (or reverse) simulation operations that use the assumed physical properties model and encoded source signatures using the same encoding functions used to encode corresponding gathers of measured data, wherein an entire simultaneous encoded gather is simulated in a single simulation operation and the simulated encoded gather and measured encoded gather are combined in a manner consistent with the iterative series selected in step (i); and

(iv) updating the model by adding the next term in the series calculated in step (iii) to the assumed model.

19. The method of claim 18, further comprising repeating steps (iii) and (iv) for at least one more term in the series.

20. A computer-implemented method for inversion of measured geophysical data to determine a physical properties model for a subsurface region, comprising:

(a) obtaining a group of two or more encoded gathers of the measured geophysical data, wherein each gather is associated with a single generalized source or, using source-receiver reciprocity, with a single receiver, and wherein each gather is encoded with a different encoding signature selected from a set non-equivalent encoding signatures;

(b) summing the encoded gathers in the group by summing all data records in each gather that correspond to a single receiver (or source if reciprocity is used), and repeating for each different receiver, resulting in a simultaneous encoded gather;

(c) assuming a physical properties model of the subsurface region, said model providing values of at least one physical property at locations throughout the subsurface region;

(d) simulating a synthetic simultaneous encoded gather corresponding to the simultaneous encoded gather of measured data, using the assumed physical properties model, wherein the simulation uses encoded source signatures using the same encoding functions used to encode the simultaneous encoded gather of measured data, wherein an entire simultaneous encoded gather is simulated in a single simulation operation;

(e) computing a cost function measuring degree of misfit between the simultaneous encoded gather of measured data and the simulated simultaneous encoded gather;

(f) repeating steps (a), (b), (d) and (e) for at least one more cycle, accumulating costs from step (e);

(g) updating the physical properties model by optimizing the accumulated costs;

(h) iterating steps (a)-(g) at least one more time using the updated physical properties model from the previous iteration as the assumed physical properties model in step (c), wherein a different set non-equivalent encoding signatures may be used for each iteration, resulting in a further updated physical properties model; and

(i) downloading the further updated physical properties model or saving it to computer storage.

21. A computer-implemented method for inversion of measured geophysical data to determine a physical properties model for a subsurface region, comprising:

(a) obtaining a group of two or more encoded gathers of the measured geophysical data, wherein each gather is associated with a single generalized source or, using source-receiver reciprocity, with a single receiver, and wherein each gather is encoded with a different encoding signature selected from a set non-equivalent encoding signatures;

(b) summing the encoded gathers in the group by summing all data records in each gather that correspond to a single receiver (or source if reciprocity is used), and repeating for each different receiver, resulting in a simultaneous encoded gather;

(c) assuming a physical properties model of the subsurface region, said model providing values of at least one physical property at locations throughout the subsurface region;

(d) selecting an iterative series solution to a scattering equation describing wave scattering in said subsurface region;

(e) beginning with the first n terms of said series, where $n \geq 1$, said first n terms corresponding to the assumed physical properties model of the subsurface region;

(f) computing the next term in the series, said calculation involving one or more encoded simultaneous source forward (or reverse) simulation operations that use the assumed physical properties model and encoded source signatures using the same encoding functions used to encode corresponding gathers of measured data, wherein an entire simultaneous encoded gather is simulated in a single simulation operation and the simulated encoded gather and measured encoded gather are combined in a manner consistent with the iterative series selected in step (d);

(g) updating the model by adding the next term in the series calculated in step (f) to the assumed model;

(h) repeating steps (f) and (g) for at least one time to add at least one more term to the series to further update the physical properties model; and

(i) downloading the farther updated physical properties model or saving it to computer storage.

22. A computer-implemented method for inversion of measured geophysical data to determine a physical properties model for a subsurface region, comprising;

(a) obtaining measured geophysical data from a geophysical survey the subsurface region;

(b) assuming ~~an initial physical properties model and~~ inverting ~~It~~ the measured data by iterative inversion involving simultaneous simulation of survey data representing a plurality of survey sources (or receivers if source-receiver reciprocity is used) wherein source signatures in the simulation are encoded, resulting in a simulated simultaneous encoded gather of geophysical data, the inversion process involving updating ~~the~~ an assumed physical properties model to reduce misfit between the simulated simultaneous encoded gather and a corresponding simultaneous encoded gather formed by summing gathers of measured survey data encoded with the same encoding functions used in the simulation; and

(c) downloading the updated physical properties model or saving it to computer storage,

23. A method for producing hydrocarbons from a subsurface region, comprising:

(a) performing a seismic survey of the subsurface region;

(b) obtaining a velocity model of the subsurface region determined by a method comprising:

~~assuming an initial velocity model and inverting it~~ measured survey data by iterative inversion involving simultaneous simulation of the seismic survey data representing a plurality of survey sources (or receivers if source-receiver reciprocity is used) wherein source signatures in the simulation are encoded, resulting in a simulated simultaneous encoded gather of geophysical data, the inversion process involving updating the an assumed velocity model to reduce misfit between the simulated simultaneous encoded gather and a corresponding simultaneous encoded gather of measured survey data encoded with the same encoding functions used in the simulation;

(c) interpreting structure in the subsurface region using the velocity model;

(d) drilling a well into a layer in the subsurface region identified at least partly from the interpreted structure; and

(e) producing hydrocarbons torn the well.

Statement under Article 19(1)

Geophysical inversion involves geophysical survey data and a model of the subsurface. See the application, for example the first sentence of paragraph 3 or the first sentence of paragraph 35. More specifically, it is the data that arc *inverted* (to infer the model). See for example the first sentence of paragraph 8; the first sentence of paragraph 13; the third sentence of paragraph 35; the first sentence of paragraph 51; or the fifth sentence of paragraph 53. In claims 22 and 23, this relationship is stated in a shorthand way, speaking of inverting a model when what is meant is "inverting [the data to infer] a model." The applicant wishes to make the wording more precise, hence the amendments.

CONCLUSION

Given the foregoing information, the applicant respectfully requests that the examiner find all claims to have industrial applicability in the Chapter II Preliminary Examination Report.

Respectfully submitted,

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J. Paul Plummer

rJ. Paul Plummet', Reg. No. 40,775
Attorney for applicant