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(54) Title: NEAR SURFACE LAYER MODELING

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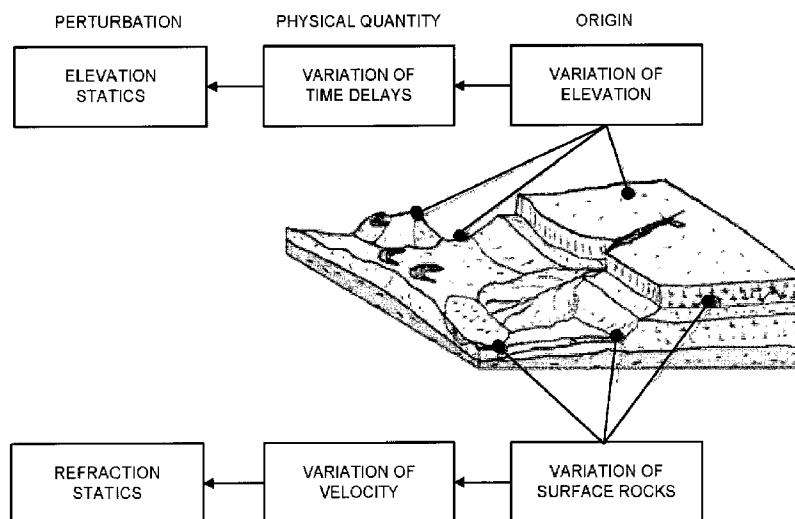


FIG. 1

(57) Abstract: A method for generating a three dimensional (3D) model of a near surface layer. In one implementation, the method may include generating a one dimensional (1D) geologic model of the near surface layer, converting the 1D geologic model to a two dimensional (2D) geologic model of the near surface layer, converting the 2D geologic model to a 3D geologic model of the near surface layer, and converting the 3D geologic model to a 3D elastic geologic model of the near surface layer.

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NEAR SURFACE LAYER MODELING

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims benefit of United States provisional patent application serial number 60/940023, filed May 24, 2007, which is incorporated herein by reference.

BACKGROUND

Field of the Invention

[0002] Implementations of various technologies described herein generally relate to seismic data processing and more particularly to near surface layer modeling.

Description of the Related Art

[0003] The following descriptions and examples do not constitute an admission as prior art by virtue of their inclusion within this section.

[0004] Variations of surface elevation and elastic properties, such as seismic velocities, result in time shifts in the surface seismic data that affect the signal level and definition of the seismic signal and render the attenuation of coherent noise difficult. The traditional method of generating an elevation model followed by a simple laterally nearly invariant velocity model often does not correct the perturbations sufficiently. For example, point-receiver data suffer from a generally lower signal and signal-to-noise level and are therefore affected by perturbations. However, point-receiver data offer access to detailed information about elevation and velocity variations in the near surface layers.

SUMMARY

[0005] Described herein are implementations of various technologies for a method for generating a three dimensional (3D) model of a near surface layer. In one implementation, the method may include generating a one dimensional (1D)

geologic model of the near surface layer, converting the 1D geologic model to a two dimensional (2D) geologic model of the near surface layer, converting the 2D geologic model to a 3D geologic model of the near surface layer, and converting the 3D geologic model to a 3D elastic geologic model of the near surface layer.

[0006] Described herein are implementations of various technologies for a computer-readable medium having stored thereon computer-executable instructions which, when executed by a computer, cause the computer to: generate a one dimensional (1D) geologic model of a near surface layer, merge multispectral remote sensing data with the 1D geologic model to generate a two dimensional (2D) geologic model of the near surface layer, and merge a digital elevation model (DEM) of the near surface layer with the 2D geologic model to generate a three dimensional (3D) geologic model of the near surface layer.

[0007] Described herein are implementations of various technologies for a computer system, which may have a processor and a memory having program instructions executable by the processor to: generate a one dimensional (1D) geologic model of a near surface layer, merge multispectral remote sensing data with the 1D geologic model to generate a two dimensional (2D) geologic model of the near surface layer, and merge a digital elevation model (DEM) of the near surface layer with the 2D geologic model to generate a three dimensional (3D) geologic model of the near surface layer, add standardized elastic rock properties to the 3D geologic model to generate a 3D elastic geologic model of the near surface layer, and calibrate the 3D elastic geologic model with seismic data, non seismic data or both.

[0008] The above referenced summary section is provided to introduce a selection of concepts in a simplified form that are further described below in the detailed description section. The summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used to limit the scope of the claimed subject matter. Furthermore, the claimed subject matter is not limited to implementations that solve any or all disadvantages noted in any part of this disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] Implementations of various technologies will hereafter be described with reference to the accompanying drawings. It should be understood, however, that the accompanying drawings illustrate only the various implementations described herein and are not meant to limit the scope of various technologies described herein.

[0010] Figure 1 illustrates a schematic diagram of the origin of perturbations in surface seismic data.

[0011] Figure 2 illustrates a process for correcting refraction static variations.

[0012] Figure 3 illustrates a method for generating a three dimensional (3D) of a near surface layer in accordance with implementations of various technologies described herein.

[0013] Figure 4 illustrates a 1D geologic model generated using a stratigraphic column and a geologic map in accordance with various implementations described herein.

[0014] Figure 5 illustrates a computing system, into which implementations of various technologies described herein may be implemented.

DETAILED DESCRIPTION

[0015] The discussion below is directed to certain specific implementations. It is to be understood that the discussion below is only for the purpose of enabling a person with ordinary skill in the art to make and use any subject matter defined now or later by the patent "claims" found in any issued patent herein.

[0016] Various techniques described herein are implemented with reference to coherent noise in near surface layer. As such, before describing implementations of these techniques, it may be useful to describe the various problems discovered in the near surface layer.

[0017] Surface seismic data suffer from heterogeneities that exist in the near surface layer. Examples of such heterogeneities include topography and lateral and

vertical variations of geology. These variations affect the propagation of seismic waves within the near surface layer by introducing locally varying time shifts into the acquired seismic data. There are two main categories of perturbations: elevation statics, which originate from variations in the topography; and refraction statics, which result from variations in the near-surface propagation velocity of P-waves. Figure 1 illustrates the origin of perturbations in surface seismic data.

[0018] State-of-the art seismic data processing distinguishes between elevation statics and refraction statics. Elevation statics may be corrected when the elevation of each sensor is known and a P-wave velocity close to the surface is assumed. Based on this assumption, refracted wave modes are identified because they propagate in the most consolidated layer close to the surface, which usually generates the first and strongest events in a seismogram. These events are referred to as first breaks. To correct elevation static variations, the sensor elevation is measured. A uniform surface velocity is assumed, which is then used to correct for the time shifts.

[0019] The correction of refraction static variations involves reliable selection of the first breaks, which in turn demands ideally constant velocity in the near surface. Under this assumption, the linear moveout of the first breaks in the XT seismogram is used to estimate the first-break velocity. Figure 2 illustrates a process for correcting refraction static variations.

[0020] The critical step for both corrections is the estimation of the correction velocities. The model, which is used in state-of-the art static corrections, is generally simple and not correlated with the prospect surface geology. The assumption that the velocities are laterally and vertically nearly constant proves unrealistic in a large number of cases. This is particularly true for point-receiver data, which suffer from generally lower signal level. Point receivers are also susceptible to the perturbations at each sensor location. Therefore, a need exists for a method for correction velocity estimation that considers the near-surface geology.

[0021] Figure 3 illustrates a method for generating a three dimensional (3D) of a near surface layer in accordance with implementations of various technologies

described herein. In one implementation, a near surface layer may be defined as the first 100 m – 150 m below the surface of the earth. At step 310, a one dimensional (1D) geologic model of a near surface layer of interest may be generated or built. The 1D geologic model may be generated by first identifying the near surface layer of interest in a geologic map that contains the near surface layer of interest. Then, the near surface layer of interest may be identified in a stratigraphic column that contains the near surface layer of interest. The 1D geologic model provides the geological time or age of the near surface layer of interest. This information may be used to assess risk for waves traveling within the near surface layer and their scattering.

[0022] Figure 4 illustrates a 1D geologic model 400 generated using a stratigraphic column 410 and a geologic map 420 in accordance with various implementations described herein. The stratigraphic column 410 may be commonly referred to as a generalized stratigraphic column, which provides an overview of the rock types, their deposition environment, and the correlation with geologic age for a large area. The geologic map 420 provides a two dimensional (2D) outline of the distribution of the rocks at the surface as well as information about the general geologic and tectonic setting of the area of interest (AOI). The rock units shown for the AOI on the geologic map allow identification of the zone of interest (ZOI) in the stratigraphic column 410. Both the AOI and the ZOI define the near surface layer of interest. Based on the information in the stratigraphic column 410 and provided by other geologic literature, the detailed stratigraphic column 430 for the ZOI can be drawn and the main stratigraphic units for the surface rocks identified. The regional geologic map 440 may provide an outline of the lateral distribution of the ZOI layers in the AOI. A schematic stratigraphic column for the surface rocks may also be provided, which assists in building the 1D geologic model 400.

[0023] At step 320, the 1D geologic model of the near surface layer of interest maybe expanded or converted to a two dimensional (2D) geologic model of the near surface layer of interest. In one implementation, multispectral remote sensing data may be merged with the 1D geologic model to generate a surface lithology map, which is the 2D geologic model. Multispectral remote sensing data are maps that

are obtained from satellite or airplane based electromagnetic sensors. They provide a multiplicity of electromagnetic readings in the visible and infrared wavelength range. Different rocks at the earth's surface may be discriminated on these maps using spectroscopy. In this manner, the multispectral remote sensing data provide the lateral information to extend the surface geologic model (1D model) to the 2D geologic model. In one implementation, the 2D geologic model may then be georeferenced and imported into a geographic information system (GIS) database. It should be understood however that the data may be georeferenced and imported at any step during this process. The 2D geologic model may be georeferenced and imported into the GIS database to ensure spatially correct correlation and interpretation of all data sets. In one implementation, the 2D geologic model may be a high resolution geologic map.

[0024] In one implementation, the multispectral remote sensing data may be decomposed into pixels by separating multi-band satellite data set into individual bands, which may be represented as image layers in the database. Each band in the image layer may then be split into individual pixels. This process may be represented by $S = \text{pixel matrix } [S_i(x,y)]$, where S represents the satellite image layer, i represents the band of satellite image in the database and (x, y) represent east and north coordinates. Once the pixel matrix is completed on a georeferenced grid, each pixel may be represented as a vector of values from each image layer, as shown in:

$$P(x,y) = (S_1, S_2, \dots S_n),$$

where n is the number of image layers in the database.

[0025] The image layers in the database may be processed using algorithms between various S_i across the entire East – North plain, which is the matrix created from all x and y values. The algorithms may include correlating pixel values from two or more image layers to provide information of consistency between the image layers, calculating the difference between pixel values to show the difference between the image layers, and any other algorithm that combines pixel values from two or more image layers, e.g., multiplying the pixel values to determine the correlation, dividing the pixel values to obtain minute differences and the like.

[0026] The multispectral remote sensing data in pixel form may then be georeferenced according to the curvature of the earth's surface. This step may include associating the earth observation data in pixel form with earth surface coordinates and warping the earth observation data in pixel form to the curvature of the earth's surface. The earth observation data in pixel form may be georeferenced using various interpolation techniques, such as one encoded in ArcView available from ESRI from Redlands, California.

[0027] At step 330, the 2D geologic model of the near surface layer of interest may be merged with a digital elevation model (DEM) of the near surface layer of interest to form or generate a three dimensional (3D) geologic model of the near surface layer of interest. DEM is a digital representation of ground surface topography or terrain. As such, the DEM provides topographical map information of the near surface layer of interest. DEM may also be known as a digital terrain model (DTM). A DEM can be represented as a raster (a grid of squares) or as a triangular irregular network. DEMs are commonly built using remote sensing techniques; however, they may also be built from land surveying. In this step, surface lithology may be converted into surface geomorphology. In one implementation, the DEM may be added to the GIS database. The geologic cross section, which may be obtained from geologic maps, may be used to identify the locations in which the surface rocks outcrop in profiles and profile photos are to be taken. The DEM provides the vertical dimension of the near surface layer of interest, depending on the outcrops that can be identified on the near surface layer of interest. In one implementation, a sequence of such outcrops may be selected. For each outcrop, a digital photo may be taken, which captures the stratigraphy of the outcrop. The top and bottom of the profile may then be measured by global positioning system (GPS) methods and the geographic data may be merged with the digital photo file to generate geotagged outcrop photos. The information available at this stage in the GIS database allows georeferencing the outcrop photos with the stratigraphic column and the near-surface geologic model.

[0028] The detailed outcrop structure may be correlated with the stratigraphic column. The geologic information available for the strata may be used to assist in

the estimate of the elastic properties of the strata required to convert the geologic model into elastic models.

[0029] At step 340, a 3D elastic geologic model of the near surface layer of interest may be generated. In one implementation, standardized elastic rock properties (i.e., V_p for P-waves, V_s for S-waves and density) may be added to the 3D geologic model of the near surface layer of interest to convert the 3D geologic model into the 3D elastic geologic model. The standardized elastic rock properties may be added to the GIS database.

[0030] At step 350, the 3D elastic geologic model may be calibrated. In one implementation, the 3D elastic geologic model may be calibrated with acquired seismic data. In such an implementation, a surface wave modeling, such as Rayleigh, Love and the like, may be applied to the 3D elastic geologic model to generate a synthetic shot record in the offset time domain. Notably, the synthetic shot record does not contain any reflection data. The synthetic shot record may then be compared with the acquired shot record of seismic data. In one implementation, the synthetic shot record may be compared only with the coherent noise portion of the acquired shot record. If it is determined that the synthetic shot record differs from the acquired shot record, then the 3D elastic geologic model may be adjusted. In one implementation, a shift may be applied in the offset time domain to adjust the 3D elastic geologic model.

[0031] In another implementation, the 3D elastic geologic model may be calibrated with the acquired shot record of seismic data as follows. Coherent noise in the near surface layer may be extracted from the acquired seismic data. A surface wave inversion (e.g., Rayleigh, Love and the like) may then be applied to the coherent noise to generate V_p for P-waves, V_s for S-waves, density and depth (thickness). These values (V_p , V_s , density and depth) may then be compared against the 3D elastic geologic model. If it is determined that these values (V_p , V_s , density and depth) differ from the 3D elastic geologic model, then the 3D elastic geologic model may be adjusted.

[0032] In addition to seismic data, the 3D elastic geologic model may also be calibrated with non seismic data, such as electro-magnetic, magnetic, electric, gravity, magneto-telluric or radar measurements. In such an implementation, the 3D elastic geologic model may be compared with the non seismic data. If it is determined that the 3D elastic geologic model varies from the non seismic data, then the 3D elastic geologic model may be adjusted.

[0033] In one implementation, a modal energy distribution may be computed for the near surface layer of interest. The modal energy distribution may be used to consider guided waves traveling within the near surface layer of interest. The modal energy distribution may be compared with the 3D elastic geologic model. If it is determined that the 3D elastic geologic model varies from the modal energy distribution, then the 3D elastic geologic model may be adjusted. In another implementation, the full elastic wavefield modes, including surface wave (e.g., Rayleigh, Love, etc.) modes, refracted (interface) wave modes and guided wave modes, may be considered.

[0034] After calibration, the 3D elastic geologic model may be used in seismic data processing. In one implementation, the 3D elastic geologic model may be used to generate a perturbation correction model. In another implementation, the 3D elastic geologic model may be used for quality control for source and receiver data since the elastic data provide coupling conditions.

[0035] Various techniques described above have many benefits. For instance, the inclusion of real-surface and near-surface geology into the velocity model for perturbation correction and its calibration with geophysical field data may provide more appropriate perturbation corrections of the field data, which may result in better continuity of the seismic reflectors, and consequently, the 3D seismic image. The representation of all data in a GIS database offers the opportunity to correlate geologic and geophysical data for data quality control during seismic data acquisition. During processing, quality control attributes obtained during surface-consistent processes, such as deconvolution, can be correlated with the elastic model and checked for their consistency.

[0036] Figure 5 illustrates a computing system 500, into which implementations of various technologies described herein may be implemented. The computing system 500 may include one or more system computers 530, which may be implemented as any conventional personal computer or server. However, those skilled in the art will appreciate that implementations of various technologies described herein may be practiced in other computer system configurations, including hypertext transfer protocol (HTTP) servers, hand-held devices, multiprocessor systems, microprocessor-based or programmable consumer electronics, network PCs, minicomputers, mainframe computers, and the like.

[0037] The system computer 530 may be in communication with disk storage devices 529, 531, and 533, which may be external hard disk storage devices. It is contemplated that disk storage devices 529, 531 and 533 are conventional hard disk drives, and as such, will be implemented by way of a local area network or by remote access. Of course, while disk storage devices 529, 531, and 533 are illustrated as separate devices, a single disk storage device may be used to store any and all of the program instructions, measurement data, and results as desired.

[0038] In one implementation, seismic data from the receivers may be stored in disk storage device 531 and non seismic data may be stored in disk storage device 533. The system computer 530 may retrieve the appropriate data from the disk storage device 531 and 533 to process seismic data according to program instructions that correspond to implementations of various technologies described herein. The program instructions may be written in a computer programming language, such as C++, Java and the like. The program instructions may be stored in a computer-readable medium, such as program disk storage device 533. Such computer-readable media may include computer storage media and communication media. Computer storage media may include volatile and non-volatile, and removable and non-removable media implemented in any method or technology for storage of information, such as computer-readable instructions, data structures, program modules or other data. Computer storage media may further include RAM, ROM, erasable programmable read-only memory (EPROM), electrically erasable programmable read-only memory (EEPROM), flash memory or other solid state

memory technology, CD-ROM, digital versatile disks (DVD), or other optical storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, or any other medium which can be used to store the desired information and which can be accessed by the system computer 430. Communication media may embody computer readable instructions, data structures, program modules or other data in a modulated data signal, such as a carrier wave or other transport mechanism and may include any information delivery media. The term "modulated data signal" may mean a signal that has one or more of its characteristics set or changed in such a manner as to encode information in the signal. By way of example, and not limitation, communication media may include wired media such as a wired network or direct-wired connection, and wireless media such as acoustic, RF, infrared and other wireless media. Combinations of any of the above may also be included within the scope of computer readable media.

[0039] In one implementation, the system computer 530 may present output primarily onto graphics display 527, or alternatively via printer 528. The system computer 530 may store the results of the methods described above on disk storage 529, which may be referred to as the GIS database. The keyboard 526 and the pointing device (e.g., a mouse, trackball, or the like) 525 may be provided with the system computer 530 to enable interactive operation.

[0040] The system computer 530 may be located at a data center remote from the survey region. The system computer 530 may be in communication with the receivers (either directly or via a recording unit, not shown), to receive signals indicative of the reflected seismic energy. These signals, after conventional formatting and other initial processing, may be stored by the system computer 530 as digital data in the disk storage 531 for subsequent retrieval and processing in the manner described above. While Figure 5 illustrates the disk storage 531 as directly connected to the system computer 530, it is also contemplated that the disk storage device 531 may be accessible through a local area network or by remote access. Furthermore, while disk storage devices 529, 531 are illustrated as separate devices for storing input seismic data and analysis results, the disk storage devices 529, 531 may be implemented within a single disk drive (either together with or separately

from program disk storage device 533), or in any other conventional manner as will be fully understood by one of skill in the art having reference to this specification.

[0041] While the foregoing is directed to implementations of various technologies described herein, other and further implementations may be devised without departing from the basic scope thereof, which may be determined by the claims that follow. Although the subject matter has been described in language specific to structural features and/or methodological acts, it is to be understood that the subject matter defined in the appended claims is not necessarily limited to the specific features or acts described above. Rather, the specific features and acts described above are disclosed as example forms of implementing the claims.

What Is Claimed Is:

1. A method for generating a three dimensional (3D) model of a near surface layer for geophysical exploration, comprising:
 - generating a one dimensional (1D) geologic model of the near surface layer;
 - converting the 1D geologic model to a two dimensional (2D) geologic model of the near surface layer;
 - converting the 2D geologic model to a 3D geologic model of the near surface layer; and
 - converting the 3D geologic model to a 3D elastic geologic model of the near surface layer.
2. The method of claim 1, wherein generating the 1D geologic model comprises identifying the near surface layer in a geological map.
3. The method of claim 1, wherein generating the 1D geologic model comprises identifying the near surface layer in a stratigraphic column.
4. The method of claim 1, wherein the 1D geologic model provides the geological age of the near surface layer.
5. The method of claim 1, wherein converting the 1D geologic model to the 2D geologic model comprises merging multispectral remote sensing data with the 1D geologic model to generate a surface lithology map.
6. The method of claim 1, further comprising georeferencing and importing the 2D geologic model into a geographic information system (GIS) database.
7. The method of claim 1, wherein converting the 2D geologic model to the 3D geologic model comprises merging a digital elevation model (DEM) of the near surface layer with the 2D geologic model.

8. The method of claim 1, wherein converting the 3D geologic model to the 3D elastic geologic model comprises adding standardized elastic rock properties to the 3D geologic model.
9. The method of claim 1, further comprising calibrating the 3D elastic geologic model with an acquired shot record of seismic data.
10. The method of claim 9, wherein calibrating the 3D elastic geologic model comprises:
 - applying a surface wave modeling to the 3D elastic geologic model to generate a synthetic shot record in an offset time domain;
 - comparing the synthetic shot record with the acquired shot record; and
 - adjusting the 3D elastic geologic model if it is determined that the synthetic shot record varies from the acquired shot record.
11. The method of claim 10, wherein adjusting the 3D elastic geologic model comprises applying a shift in the offset time domain.
12. The method of claim 10, wherein the surface wave modeling is a Rayleigh wave modeling.
13. The method of claim 9, wherein calibrating the 3D elastic geologic model comprises:
 - applying a surface wave modeling to the 3D elastic geologic model to generate a synthetic shot record in an offset time domain;
 - comparing the synthetic shot record with only the coherent noise portion of the acquired shot record; and
 - adjusting the 3D elastic geologic model if it is determined that the synthetic shot record varies from the acquired shot record.

14. The method of claim 9, wherein calibrating the 3D elastic geologic model comprises:
- extracting coherent noise in the near surface layer from the acquired shot record;
 - applying a surface wave inversion to the coherent noise to generate Vp, Vs, density and depth values;
 - comparing the Vp, Vs, density and depth values with the 3D elastic geologic model; and
 - adjusting the 3D elastic geologic model if it is determined that the Vp, Vs, density and depth values vary from the 3D elastic geologic model.
15. The method of claim 1, further comprising calibrating the 3D elastic geologic model with non seismic data.
16. The method of claim 15, wherein the non seismic data comprises electro-magnetic, magnetic, electric, gravity, magneto-telluric, radar measurements or combinations thereof.
17. The method of claim 1, further comprising calibrating the 3D elastic geologic model by:
- computing a modal energy distribution of the near surface layer;
 - comparing the modal energy distribution with the 3D elastic geologic model; and
 - adjusting the 3D elastic geologic model if it is determined that the modal energy distribution varies from the 3D elastic geologic model.
18. A data processing system for geophysical exploration, comprising:
- a processor; and
 - a memory comprising program instructions executable by the processor to perform a method as in any claims 1-17.

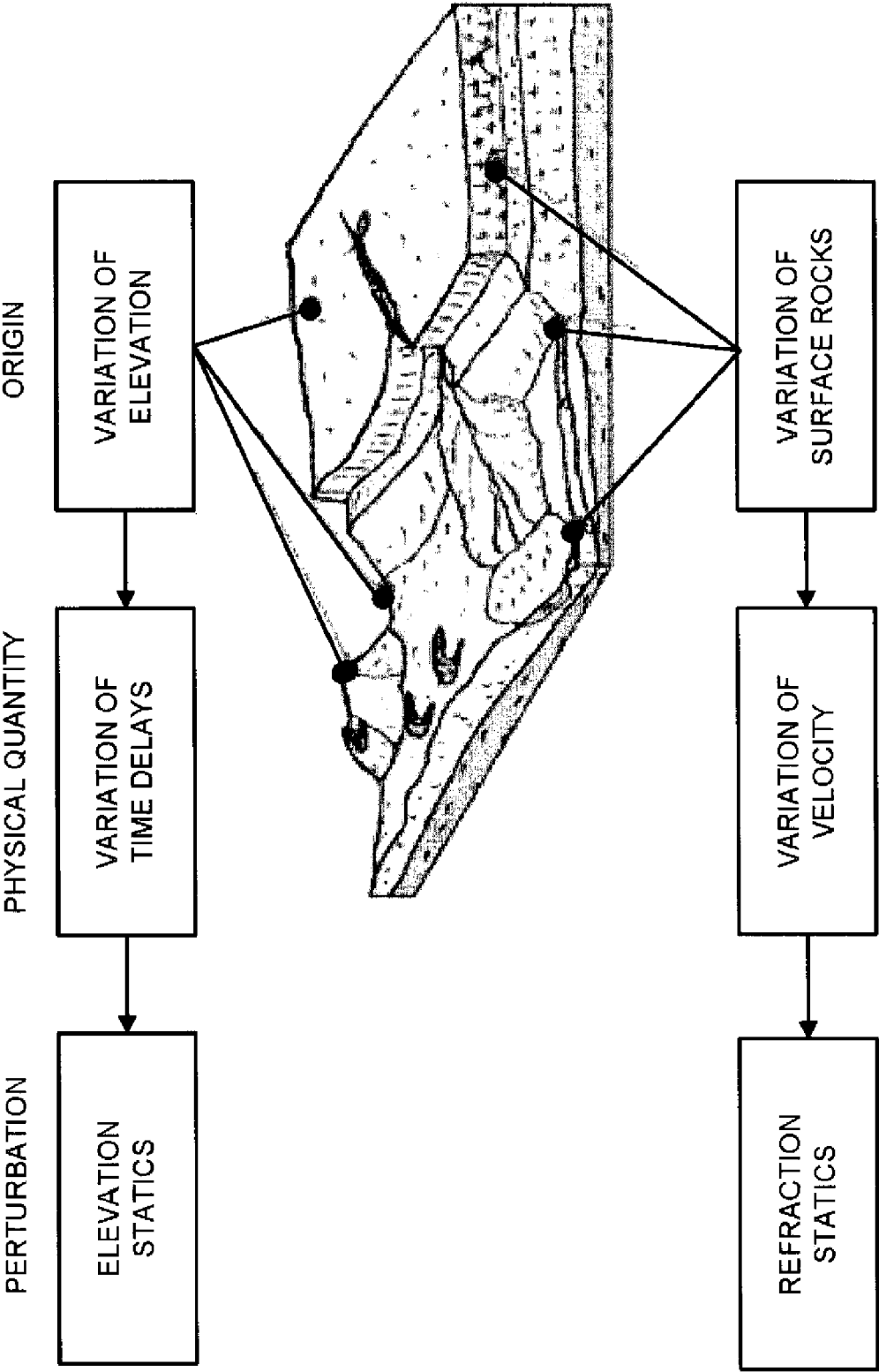
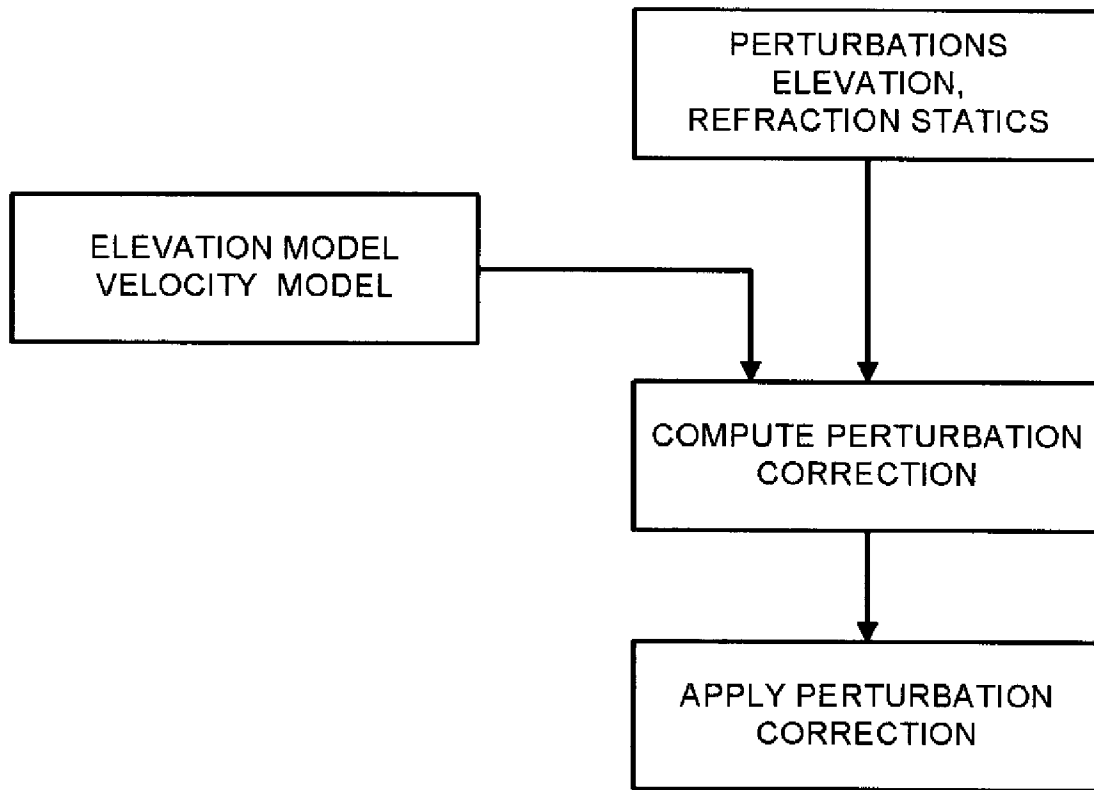
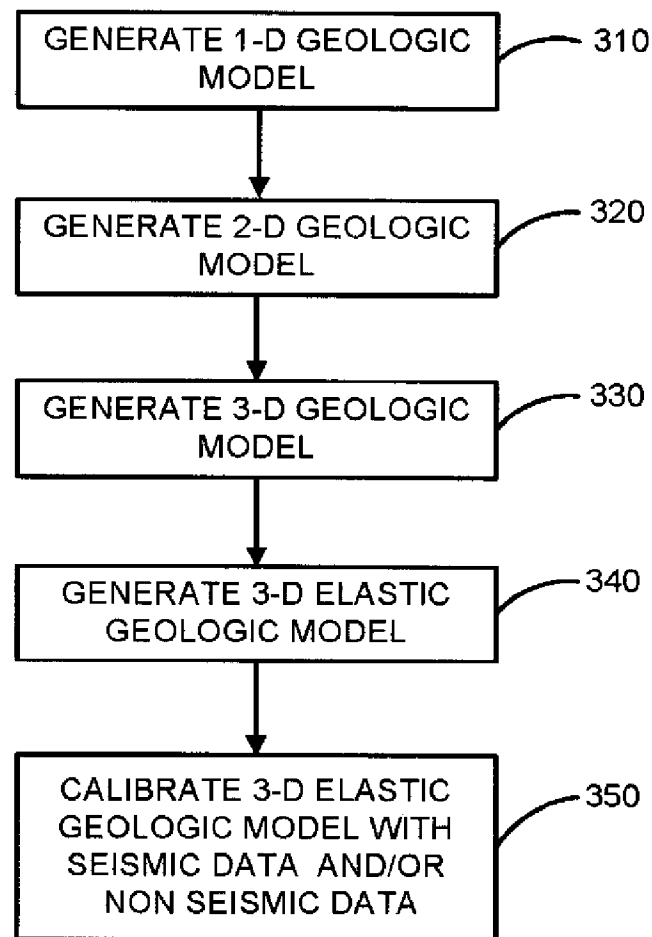


FIG. 1

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200**FIG. 2**

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300**FIG. 3**

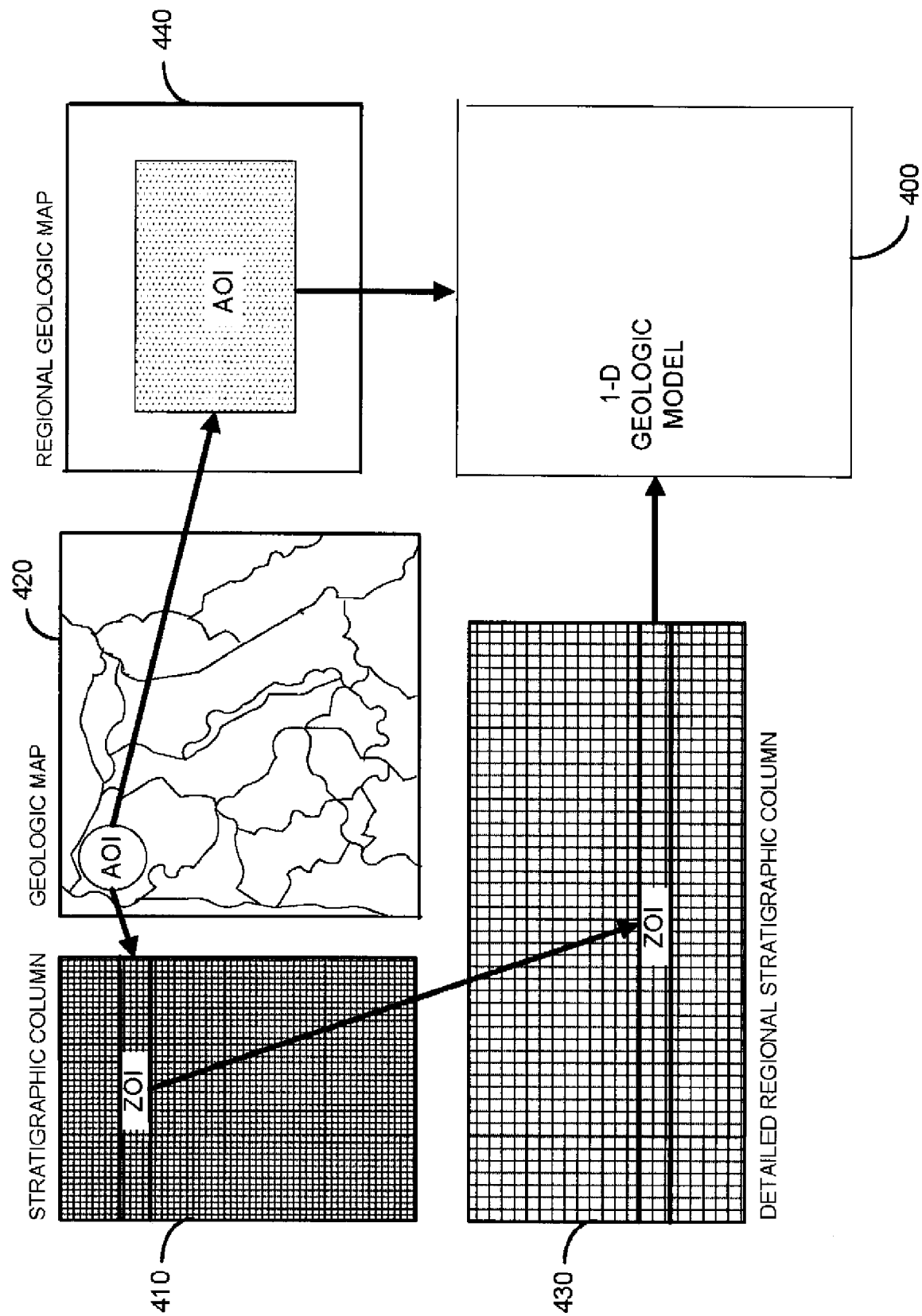
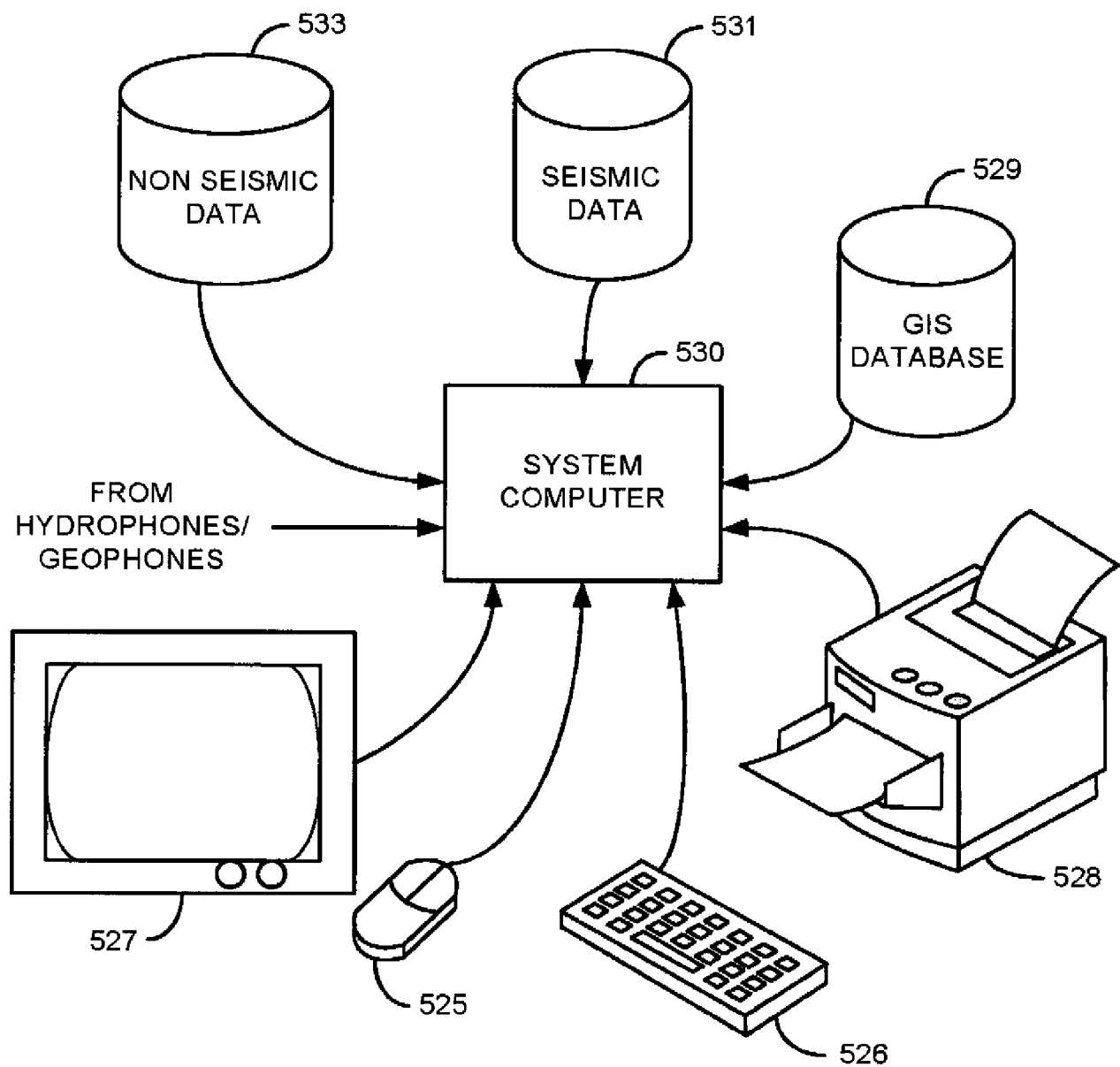


FIG. 4

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500**FIG. 5**

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2008/064357

A. CLASSIFICATION OF SUBJECT MATTER

INV. G01V11/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G01V

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal; WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2005/114031 A1 (MICHAEL THAMBYNAYAGAM RAJ K [GB] ET AL THAMBYNAYAGAM RAJ KUMAR MICHAEL) 26 May 2005 (2005-05-26) paragraphs [0003], [0028], [0033], [0037], [0039], [0041], [0048] figures 8-11	1-18
X	WO 2005/119298 A (SCHLUMBERGER HOLDINGS [VG]; SCHLUMBERGER SERVICES PETROL [FR]; MADATOV) 15 December 2005 (2005-12-15) page 4, line 13 - line 18 page 12, line 2 - line 10 page 16, line 22 - page 17, line 14 page 23, line 23 - line 26 figure 4	1-18



Further documents are listed in the continuation of Box C.



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Date of the actual completion of the international search

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INTERNATIONAL SEARCH REPORT

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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X	PFLEIDERER S ET AL: "3D-visualisation of Vienna's subsurface" OFFSHORE EUROPE PROCEEDINGS, XX, XX, no. SPE 65132, 1 February 2004 (2004-02-01), pages 367-371, XP002354091 pages 367, 368 page 370; figure 5	1-18
X	US 5 671 136 A (WILLHOIT JR LOUIS E [US]) 23 September 1997 (1997-09-23) column 8, line 36 - line 50 column 28, line 36 - column 29, line 6 column 31, line 48 - column 32, line 4 figure 7B	1-18
A	US 2005/171700 A1 (DEAN WILLIAM K [US]) 4 August 2005 (2005-08-04) paragraphs [0046], [0098], [0102]	1-18
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