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(54) Title: DIP ESTIMATION VIA A MODIFIED STRUCTURE TENSOR

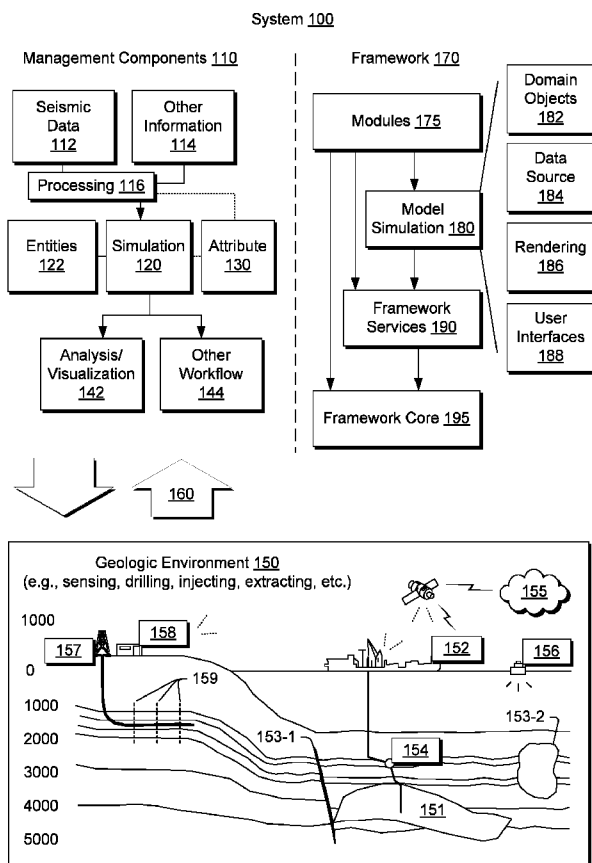


Fig. 1

(57) Abstract: A method can include receiving a gradient field derived from seismic data of a three-dimensional subterranean environment; determining a modified structure tensor based at least in part on the gradient field; and estimating a dip field based at least in part on the modified structure tensor.



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DIP ESTIMATION VIA A MODIFIED STRUCTURE TENSOR

BACKGROUND

[0001] Seismic interpretation is a process that may examine seismic data (e.g., location and time or depth) in an effort to identify subsurface structures such as horizons and faults. Structures may be, for example, faulted stratigraphic formations indicative of hydrocarbon traps or flow channels. In the field of resource extraction, enhancements to seismic interpretation can allow for construction of a more accurate model, which, in turn, may improve seismic volume analysis for purposes of resource extraction. Various techniques described herein pertain to processing of seismic data, for example, for analysis of such data to characterize one or more regions in a geologic environment and, for example, to perform one or more operations (e.g., field operations, etc.).

SUMMARY

[0002] A method can include receiving a gradient field derived from seismic data of a three-dimensional subterranean environment; determining a modified structure tensor based at least in part on the gradient field; and estimating a dip field based at least in part on the modified structure tensor. A system can include a processor; memory operatively coupled to the processor; and processor-executable instructions stored in the memory to instruct the system where the instructions include instructions to receive a gradient field derived from seismic data of a three-dimensional subterranean environment; determine a modified structure tensor based at least in part on the gradient field; and estimate a dip field based at least in part on the modified structure tensor. One or more computer-readable storage media can include computer-executable instructions to instruct a computer where the instructions include instructions to: receive a gradient field derived from seismic data of a three-dimensional subterranean environment; determine a modified structure tensor based at least in part on the gradient field; and estimate a dip field based at least in part on the modified structure tensor. Various other apparatuses, systems, methods, etc., are also disclosed.

[0003] This summary is provided to introduce a selection of concepts that are further described below in the detailed description. This summary is not intended to identify key or essential features of the claimed subject matter, nor is it intended to be used as an aid in limiting the scope of the claimed subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] Features and advantages of the described implementations can be more readily understood by reference to the following description taken in conjunction with the accompanying drawings.

[0005] Fig. 1 illustrates an example system that includes various components for modeling a geologic environment and various equipment associated with the geologic environment;

[0006] Fig. 2 illustrates an example of a sedimentary basin, an example of a method, an example of a formation, an example of a borehole, an example of a borehole tool, an example of a convention and an example of a system;

[0007] Fig. 3 illustrates examples of techniques that may acquire data;

[0008] Fig. 4 illustrates examples of signals, an example of a technique, examples of data, etc.;

[0009] Fig. 5 illustrates an example of a method;

[0010] Fig. 6 illustrates examples of graphics of information and processing of such information;

[0011] Fig. 7 illustrates an example of a graphical user interface;

[0012] Fig. 8 illustrates an example of a graphical user interface;

[0013] Fig. 9 illustrates an example of a method;

[0014] Fig. 10 illustrates examples of some different types of structural environments; and

[0015] Fig. 11 illustrates example components of a system and a networked system.

DETAILED DESCRIPTION

[0016] This description is not to be taken in a limiting sense, but rather is made merely for the purpose of describing the general principles of the

implementations. The scope of the described implementations should be ascertained with reference to the issued claims.

[0017] Seismic interpretation is a process that involves examining seismic data (e.g., with respect to location and time or depth) to identify one or more types of subsurface structures (e.g., horizons, faults, geobodies, etc.). When performing seismic interpretation, seismic data may be provided in the form of traces where, for example, each trace is an amplitude versus time recording of energy emitted by a source that has interacted with various subsurface structures. An interpretation process may involve visual display of seismic data and interaction using one or more tools (e.g., executable instruction modules stored in memory and executed by one or more processors). An interpretation process may consider vertical seismic sections, inline and crossline directions, horizontal seismic sections called horizontal time slices, etc. Seismic data may optionally be interpreted with other data such as, for example, well log data. As an example, a process may include performing an inversion to generate a model. For example, seismic data and optionally other data may be used in a method that includes by solving an inverse problem to generate a model of a subsurface region. Such a model may be, for example, an acoustic impedance model and/or other type of model.

[0018] As an example, an interpretation process may include receiving seismic data from a data store (e.g., via a network or other connection). Seismic data may be formatted according to one of the SEG-Y format standards (Society of Exploration Geophysicists), the ZGY format standard (e.g., a bricked format) or another format. As an example, seismic data may be stored with trace header information, which may assist in analysis of the seismic data. Seismic data may optionally be accessed, for example, according to a number of traces (e.g., in an inline, crossline or inline and crossline directions), which may be entire traces or portions thereof (e.g., for one or more particular times or depths). As an example, given a number of traces across a region, a process may access some of those traces in a sub-region by specifying inline and crossline indexes (e.g., or geographic or grid coordinates) as well as a time or depth window.

[0019] A process may include determining one or more seismic attributes. A seismic attribute may be considered, for example, a way to describe, quantify, etc., characteristic content of seismic data. As an example, a quantified characteristic

may be computed, measured, etc., from seismic data. A seismic attribute may be a rate of change of a quantity (or quantities) with respect to time, space or both time and space. As an example, a seismic attribute may provide for examination of seismic data in an amplitude domain, in a time domain, or in another manner. As an example, a seismic attribute may be based on another seismic attribute (e.g., a second derivative seismic attribute may be based on a first derivative seismic attribute, etc.).

[0020] A framework may include modules (e.g., processor-executable instructions stored in memory) to determine one or more seismic attributes. Seismic attributes may optionally be classified, for example, as volume attributes or surface attributes or one-dimensional attributes. As an example, a volume attribute may be an attribute computed from a seismic cube and may result in a new seismic cube that includes information pertaining to the volume attribute. As an example, a surface attribute may be a value associated with a surface of a seismic cube that includes information pertaining to a volume attribute.

[0021] A seismic interpretation may be performed using displayable information, for example, by rendering information to a display device, a projection device, a printing device, etc. As an example, one or more color schemes (e.g., optionally including black and white or greyscale) may be referenced for displayable information to enhance visual examination of the displayable information. A color scheme may include a palette, a range, etc. A look-up-table (LUT) or other data structure, function (e.g., linear or non-linear), etc., may allow for mapping of values associated with one or more seismic attributes to intensity, colors (e.g., RGB, YCbCr, etc.), etc. Where the human eye will be used or is used for viewing displayable information, a display scheme may be selected to enhance interpretation (e.g., to increase contrast, provide for blinking, etc.).

[0022] A module for determining one or more seismic attributes may include one or more parameters. As an example, a module may include one or more parameters that may be set via a graphical user interface (GUI), a specification file, etc. In such an example, an interpreter may wish to examine a seismic attribute for seismic data using one or more values of a parameter. As an example, such a module may provide a default value and a field, graphical control, etc., that allows for input of a value other than the default value.

[0023] As an example, seismic interpretation may be performed using seismic to simulation software such as the PETREL® seismic to simulation software framework (Schlumberger Limited, Houston, Texas), which includes various features to perform attribute analyses (e.g., with respect to a 3D seismic cube, a 2D seismic line, etc.). While the PETREL® seismic to simulation software framework is mentioned, other types of software, frameworks, etc., may be employed for purposes of attribute analyses.

[0024] Fig. 1 shows an example of a system 100 that includes various management components 110 to manage various aspects of a geologic environment 150 (e.g., an environment that includes a sedimentary basin, a reservoir 151, one or more faults 153-1, one or more geobodies 153-2, etc.). For example, the management components 110 may allow for direct or indirect management of sensing, drilling, injecting, extracting, etc., with respect to the geologic environment 150. In turn, further information about the geologic environment 150 may become available as feedback 160 (e.g., optionally as input to one or more of the management components 110).

[0025] In the example of Fig. 1, the management components 110 include a seismic data component 112, an additional information component 114 (e.g., well/logging data), a processing component 116, a simulation component 120, an attribute component 130, an analysis/visualization component 142 and a workflow component 144. In operation, seismic data and other information provided per the components 112 and 114 may be input to the simulation component 120.

[0026] In an example embodiment, the simulation component 120 may rely on entities 122. Entities 122 may include earth entities or geological objects such as wells, surfaces, bodies, reservoirs, etc. In the system 100, the entities 122 can include virtual representations of actual physical entities that are reconstructed for purposes of simulation. The entities 122 may include entities based on data acquired via sensing, observation, etc. (e.g., the seismic data 112 and other information 114). An entity may be characterized by one or more properties (e.g., a geometrical pillar grid entity of an earth model may be characterized by a porosity property). Such properties may represent one or more measurements (e.g., acquired data), calculations, etc.

[0027] In an example embodiment, the simulation component 120 may operate in conjunction with a software framework such as an object-based framework. In such a framework, entities may include entities based on pre-defined classes to facilitate modeling and simulation. A commercially available example of an object-based framework is the MICROSOFT® .NET™ framework (Redmond, Washington), which provides a set of extensible object classes. In the .NET™ framework, an object class encapsulates a module of reusable code and associated data structures. Object classes can be used to instantiate object instances for use in by a program, script, etc. For example, borehole classes may define objects for representing boreholes based on well data.

[0028] In the example of Fig. 1, the simulation component 120 may process information to conform to one or more attributes specified by the attribute component 130, which may include a library of attributes. Such processing may occur prior to input to the simulation component 120 (e.g., consider the processing component 116). As an example, the simulation component 120 may perform operations on input information based on one or more attributes specified by the attribute component 130. In an example embodiment, the simulation component 120 may construct one or more models of the geologic environment 150, which may be relied on to simulate behavior of the geologic environment 150 (e.g., responsive to one or more acts, whether natural or artificial). In the example of Fig. 1, the analysis/visualization component 142 may allow for interaction with a model or model-based results (e.g., simulation results, etc.). As an example, output from the simulation component 120 may be input to one or more other workflows, as indicated by a workflow component 144.

[0029] As an example, the simulation component 120 may include one or more features of a simulator such as the ECLIPSE® reservoir simulator (Schlumberger Limited, Houston Texas), the INTERSECT™ reservoir simulator (Schlumberger Limited, Houston Texas), etc. As an example, a simulation component, a simulator, etc. may include features to implement one or more meshless techniques (e.g., to solve one or more equations, etc.). As an example, a reservoir or reservoirs may be simulated with respect to one or more enhanced recovery techniques (e.g., consider a thermal process such as SAGD, etc.).

[0030] In an example embodiment, the management components 110 may include features of a commercially available framework such as the PETREL® seismic to simulation software framework (Schlumberger Limited, Houston, Texas). The PETREL® framework provides components that allow for optimization of exploration and development operations. The PETREL® framework includes seismic to simulation software components that can output information for use in increasing reservoir performance, for example, by improving asset team productivity. Through use of such a framework, various professionals (e.g., geophysicists, geologists, and reservoir engineers) can develop collaborative workflows and integrate operations to streamline processes. Such a framework may be considered an application and may be considered a data-driven application (e.g., where data is input for purposes of modeling, simulating, etc.).

[0031] In an example embodiment, various aspects of the management components 110 may include add-ons or plug-ins that operate according to specifications of a framework environment. For example, a commercially available framework environment marketed as the OCEAN® framework environment (Schlumberger Limited, Houston, Texas) allows for integration of add-ons (or plug-ins) into a PETREL® framework workflow. The OCEAN® framework environment leverages .NET® tools (Microsoft Corporation, Redmond, Washington) and offers stable, user-friendly interfaces for efficient development. In an example embodiment, various components may be implemented as add-ons (or plug-ins) that conform to and operate according to specifications of a framework environment (e.g., according to application programming interface (API) specifications, etc.).

[0032] Fig. 1 also shows an example of a framework 170 that includes a model simulation layer 180 along with a framework services layer 190, a framework core layer 195 and a modules layer 175. The framework 170 may include the commercially available OCEAN® framework where the model simulation layer 180 is the commercially available PETREL® model-centric software package that hosts OCEAN® framework applications. In an example embodiment, the PETREL® software may be considered a data-driven application. The PETREL® software can include a framework for model building and visualization.

[0033] As an example, a framework may include features for implementing one or more mesh generation techniques. For example, a framework may include

an input component for receipt of information from interpretation of seismic data, one or more attributes based at least in part on seismic data, log data, image data, etc. Such a framework may include a mesh generation component that processes input information, optionally in conjunction with other information, to generate a mesh.

[0034] In the example of Fig. 1, the model simulation layer 180 may provide domain objects 182, act as a data source 184, provide for rendering 186 and provide for various user interfaces 188. Rendering 186 may provide a graphical environment in which applications can display their data while the user interfaces 188 may provide a common look and feel for application user interface components.

[0035] As an example, the domain objects 182 can include entity objects, property objects and optionally other objects. Entity objects may be used to geometrically represent wells, surfaces, bodies, reservoirs, etc., while property objects may be used to provide property values as well as data versions and display parameters. For example, an entity object may represent a well where a property object provides log information as well as version information and display information (e.g., to display the well as part of a model).

[0036] In the example of Fig. 1, data may be stored in one or more data sources (or data stores, generally physical data storage devices), which may be at the same or different physical sites and accessible via one or more networks. The model simulation layer 180 may be configured to model projects. As such, a particular project may be stored where stored project information may include inputs, models, results and cases. Thus, upon completion of a modeling session, a user may store a project. At a later time, the project can be accessed and restored using the model simulation layer 180, which can recreate instances of the relevant domain objects.

[0037] In the example of Fig. 1, the geologic environment 150 may include layers (e.g., stratification) that include a reservoir 151 and one or more other features such as the fault 153-1, the geobody 153-2, etc. As an example, the geologic environment 150 may be outfitted with any of a variety of sensors, detectors, actuators, etc. For example, equipment 152 may include communication circuitry to receive and to transmit information with respect to one or more networks 155. Such information may include information associated with downhole equipment 154, which may be equipment to acquire information, to assist with resource recovery, etc.

Other equipment 156 may be located remote from a well site and include sensing, detecting, emitting or other circuitry. Such equipment may include storage and communication circuitry to store and to communicate data, instructions, etc. As an example, one or more satellites may be provided for purposes of communications, data acquisition, etc. For example, Fig. 1 shows a satellite in communication with the network 155 that may be configured for communications, noting that the satellite may additionally or alternatively include circuitry for imagery (e.g., spatial, spectral, temporal, radiometric, etc.).

[0038] Fig. 1 also shows the geologic environment 150 as optionally including equipment 157 and 158 associated with a well that includes a substantially horizontal portion that may intersect with one or more fractures 159. For example, consider a well in a shale formation that may include natural fractures, artificial fractures (e.g., hydraulic fractures) or a combination of natural and artificial fractures. As an example, a well may be drilled for a reservoir that is laterally extensive. In such an example, lateral variations in properties, stresses, etc. may exist where an assessment of such variations may assist with planning, operations, etc. to develop a laterally extensive reservoir (e.g., via fracturing, injecting, extracting, etc.). As an example, the equipment 157 and/or 158 may include components, a system, systems, etc. for fracturing, seismic sensing, analysis of seismic data, assessment of one or more fractures, etc.

[0039] As mentioned, the system 100 may be used to perform one or more workflows. A workflow may be a process that includes a number of worksteps. A workstep may operate on data, for example, to create new data, to update existing data, etc. As an example, a may operate on one or more inputs and create one or more results, for example, based on one or more algorithms. As an example, a system may include a workflow editor for creation, editing, executing, etc. of a workflow. In such an example, the workflow editor may provide for selection of one or more pre-defined worksteps, one or more customized worksteps, etc. As an example, a workflow may be a workflow implementable in the PETREL® software, for example, that operates on seismic data, seismic attribute(s), etc. As an example, a workflow may be a process implementable in the OCEAN® framework. As an example, a workflow may include one or more worksteps that access a module such as a plug-in (e.g., external executable code, etc.).

[0040] Fig. 2 shows an example of a sedimentary basin 210 (e.g., a geologic environment), an example of a method 220 for model building (e.g., for a simulator, etc.), an example of a formation 230, an example of a borehole 235 in a formation, an example of a convention 240 and an example of a system 250.

[0041] As an example, reservoir simulation, petroleum systems modeling, etc. may be applied to characterize various types of subsurface environments, including environments such as those of Fig. 1.

[0042] In Fig. 2, the sedimentary basin 210, which is a geologic environment, includes horizons, faults, one or more geobodies and facies formed over some period of geologic time. These features are distributed in two or three dimensions in space, for example, with respect to a Cartesian coordinate system (e.g., x, y and z) or other coordinate system (e.g., cylindrical, spherical, etc.). As shown, the model building method 220 includes a data acquisition block 224 and a model geometry block 228. Some data may be involved in building an initial model and, thereafter, the model may optionally be updated in response to model output, changes in time, physical phenomena, additional data, etc. As an example, data for modeling may include one or more of the following: depth or thickness maps and fault geometries and timing from seismic, remote-sensing, electromagnetic, gravity, outcrop and well log data. Furthermore, data may include depth and thickness maps stemming from facies variations (e.g., due to seismic unconformities) assumed to following geological events ("iso" times) and data may include lateral facies variations (e.g., due to lateral variation in sedimentation characteristics).

[0043] To proceed to modeling of geological processes, data may be provided, for example, data such as geochemical data (e.g., temperature, kerogen type, organic richness, etc.), timing data (e.g., from paleontology, radiometric dating, magnetic reversals, rock and fluid properties, etc.) and boundary condition data (e.g., heat-flow history, surface temperature, paleowater depth, etc.).

[0044] In basin and petroleum systems modeling, quantities such as temperature, pressure and porosity distributions within the sediments may be modeled, for example, by solving partial differential equations (PDEs) using one or more numerical techniques. Modeling may also model geometry with respect to time, for example, to account for changes stemming from geological events (e.g., deposition of material, erosion of material, shifting of material, etc.).

[0045] A commercially available modeling framework marketed as the PETROMOD® framework (Schlumberger Limited, Houston, Texas) includes features for input of various types of information (e.g., seismic, well, geological, etc.) to model evolution of a sedimentary basin. The PETROMOD® framework provides for petroleum systems modeling via input of various data such as seismic data, well data and other geological data, for example, to model evolution of a sedimentary basin. The PETROMOD® framework may predict if, and how, a reservoir has been charged with hydrocarbons, including, for example, the source and timing of hydrocarbon generation, migration routes, quantities, pore pressure and hydrocarbon type in the subsurface or at surface conditions. In combination with a framework such as the PETREL® framework, workflows may be constructed to provide basin-to-prospect scale exploration solutions. Data exchange between frameworks can facilitate construction of models, analysis of data (e.g., PETROMOD® framework data analyzed using PETREL® framework capabilities), and coupling of workflows.

[0046] As shown in Fig. 2, the formation 230 includes a horizontal surface and various subsurface layers. As an example, a borehole may be vertical. As another example, a borehole may be deviated. In the example of Fig. 2, the borehole 235 may be considered a vertical borehole, for example, where the z-axis extends downwardly normal to the horizontal surface of the formation 230. As an example, a tool 237 may be positioned in a borehole, for example, to acquire information. As mentioned, a borehole tool may be configured to acquire electrical borehole images. As an example, the fullbore Formation MicroImager (FMI) tool (Schlumberger Limited, Houston, Texas) can acquire borehole image data. A data acquisition sequence for such a tool can include running the tool into a borehole with acquisition pads closed, opening and pressing the pads against a wall of the borehole, delivering electrical current into the material defining the borehole while translating the tool in the borehole, and sensing current remotely, which is altered by interactions with the material.

[0047] As an example, a borehole may be vertical, deviate and/or horizontal. As an example, a tool may be positioned to acquire information in a horizontal portion of a borehole. Analysis of such information may reveal vugs, dissolution planes (e.g., dissolution along bedding planes), stress-related features, dip events,

etc. As an example, a tool may acquire information that may help to characterize a fractured reservoir, optionally where fractures may be natural and/or artificial (e.g., hydraulic fractures). Such information may assist with completions, stimulation treatment, etc. As an example, information acquired by a tool may be analyzed using a framework such as the TECHLOG® framework (Schlumberger Limited, Houston, Texas).

[0048] As to the convention 240 for dip, as shown, the three dimensional orientation of a plane can be defined by its dip and strike. Dip is the angle of slope of a plane from a horizontal plane (e.g., an imaginary plane) measured in a vertical plane in a specific direction. Dip may be defined by magnitude (e.g., also known as angle or amount) and azimuth (e.g., also known as direction). As shown in the convention 240 of Fig. 2, various angles ϕ indicate angle of slope downwards, for example, from an imaginary horizontal plane (e.g., flat upper surface); whereas, dip refers to the direction towards which a dipping plane slopes (e.g., which may be given with respect to degrees, compass directions, etc.). Another feature shown in the convention of Fig. 2 is strike, which is the orientation of the line created by the intersection of a dipping plane and a horizontal plane (e.g., consider the flat upper surface as being an imaginary horizontal plane).

[0049] Some additional terms related to dip and strike may apply to an analysis, for example, depending on circumstances, orientation of collected data, etc. One term is “true dip” (see, e.g., Dip_T in the convention 240 of Fig. 2). True dip is the dip of a plane measured directly perpendicular to strike (see, e.g., line directed northwardly and labeled “strike” and angle α_{90}) and also the maximum possible value of dip magnitude. Another term is “apparent dip” (see, e.g., Dip_A in the convention 240 of Fig. 2). Apparent dip may be the dip of a plane as measured in any other direction except in the direction of true dip (see, e.g., ϕ_A as Dip_A for angle α); however, it is possible that the apparent dip is equal to the true dip (see, e.g., ϕ as $\text{Dip}_A = \text{Dip}_T$ for angle α_{90} with respect to the strike). In other words, where the term apparent dip is used (e.g., in a method, analysis, algorithm, etc.), for a particular dipping plane, a value for “apparent dip” may be equivalent to the true dip of that particular dipping plane.

[0050] As shown in the convention 240 of Fig. 2, the dip of a plane as seen in a cross-section perpendicular to the strike is true dip (see, e.g., the surface with ϕ as

$Dip_A = Dip_T$ for angle α_{90} with respect to the strike). As indicated, dip observed in a cross-section in any other direction is apparent dip (see, e.g., surfaces labeled Dip_A). Further, as shown in the convention 240 of Fig. 2, apparent dip may be approximately 0 degrees (e.g., parallel to a horizontal surface where an edge of a cutting plane runs along a strike direction).

[0051] In terms of observing dip in wellbores, true dip is observed in wells drilled vertically. In wells drilled in any other orientation (or deviation), the dips observed are apparent dips (e.g., which are referred to by some as relative dips). In order to determine true dip values for planes observed in such boreholes, as an example, a vector computation (e.g., based on the borehole deviation) may be applied to one or more apparent dip values.

[0052] As mentioned, another term that finds use in sedimentological interpretations from borehole images is “relative dip” (e.g., Dip_R). A value of true dip measured from borehole images in rocks deposited in very calm environments may be subtracted (e.g., using vector-subtraction) from dips in a sand body. In such an example, the resulting dips are called relative dips and may find use in interpreting sand body orientation.

[0053] A convention such as the convention 240 may be used with respect to an analysis, an interpretation, an attribute, etc. (see, e.g., various blocks of the system 100 of Fig. 1). As an example, various types of features may be described, in part, by dip (e.g., sedimentary bedding, faults and fractures, cuestas, igneous dikes and sills, metamorphic foliation, etc.). As an example, dip may change spatially as a layer approaches a geobody. For example, consider a salt body that may rise due to various forces (e.g., buoyancy, etc.). In such an example, dip may trend upward as a salt body moves upward.

[0054] Seismic interpretation may aim to identify and/or classify one or more subsurface boundaries based at least in part on one or more dip parameters (e.g., angle or magnitude, azimuth, etc.). As an example, various types of features (e.g., sedimentary bedding, faults and fractures, cuestas, igneous dikes and sills, metamorphic foliation, etc.) may be described at least in part by angle, at least in part by azimuth, etc.

[0055] As an example, equations may be provided for petroleum expulsion and migration, which may be modeled and simulated, for example, with respect to a

period of time. Petroleum migration from a source material (e.g., primary migration or expulsion) may include use of a saturation model where migration-saturation values control expulsion. Determinations as to secondary migration of petroleum (e.g., oil or gas), may include using hydrodynamic potential of fluid and accounting for driving forces that promote fluid flow. Such forces can include buoyancy gradient, pore pressure gradient, and capillary pressure gradient.

[0056] As shown in Fig. 2, the system 250 includes one or more information storage devices 252, one or more computers 254, one or more networks 260 and one or more modules 270. As to the one or more computers 254, each computer may include one or more processors (e.g., or processing cores) 256 and memory 258 for storing instructions (e.g., modules), for example, executable by at least one of the one or more processors. As an example, a computer may include one or more network interfaces (e.g., wired or wireless), one or more graphics cards, a display interface (e.g., wired or wireless), etc. As an example, imagery such as surface imagery (e.g., satellite, geological, geophysical, etc.) may be stored, processed, communicated, etc. As an example, data may include SAR data, GPS data, etc. and may be stored, for example, in one or more of the storage devices 252.

[0057] As an example, the one or more modules 270 may include instructions (e.g., stored in memory) executable by one or more processors to instruct the system 250 to perform various actions. As an example, the system 250 may be configured such that the one or more modules 270 provide for establishing the framework 170 of Fig. 1 or a portion thereof. As an example, one or more methods, techniques, etc. may be performed using one or more modules, which may be, for example, one or more of the one or more modules 270 of Fig. 2.

[0058] As mentioned, seismic data may be acquired and analyzed to understand better subsurface structure of a geologic environment. Reflection seismology finds use in geophysics, for example, to estimate properties of subsurface formations. As an example, reflection seismology may provide seismic data representing waves of elastic energy (e.g., as transmitted by P-waves and S-waves, in a frequency range of approximately 1 Hz to approximately 100 Hz or optionally less than 1 Hz and/or optionally more than 100 Hz). Seismic data may be

processed and interpreted, for example, to understand better composition, fluid content, extent and geometry of subsurface rocks.

[0059] Fig. 3 shows an example of an acquisition technique 340 to acquire seismic data (see, e.g., data 360). As an example, a system may process data acquired by the technique 340, for example, to allow for direct or indirect management of sensing, drilling, injecting, extracting, etc., with respect to a geologic environment. In turn, further information about the geologic environment may become available as feedback (e.g., optionally as input to the system). As an example, an operation may pertain to a reservoir that exists in a geologic environment such as, for example, a reservoir. As an example, a technique may provide information (e.g., as an output) that may specify one or more location coordinates of a feature in a geologic environment, one or more characteristics of a feature in a geologic environment, etc.

[0060] In Fig. 3, the technique 340 may be implemented with respect to a geologic environment 341. As shown, an energy source (e.g., a transmitter) 342 may emit energy where the energy travels as waves that interact with the geologic environment 341. As an example, the geologic environment 341 may include a bore 343 where one or more sensors (e.g., receivers) 344 may be positioned in the bore 343. As an example, energy emitted by the energy source 342 may interact with a layer (e.g., a structure, an interface, etc.) 345 in the geologic environment 341 such that a portion of the energy is reflected, which may then be sensed by one or more of the sensors 344. Such energy may be reflected as an upgoing primary wave (e.g., or “primary” or “singly” reflected wave). As an example, a portion of emitted energy may be reflected by more than one structure in the geologic environment and referred to as a multiple reflected wave (e.g., or “multiple”). For example, the geologic environment 341 is shown as including a layer 347 that resides below a surface layer 349. Given such an environment and arrangement of the source 342 and the one or more sensors 344, energy may be sensed as being associated with particular types of waves.

[0061] As an example, a “multiple” may refer to multiply reflected seismic energy or, for example, an event in seismic data that has incurred more than one reflection in its travel path. As an example, depending on a time delay from a primary event with which a multiple may be associated, a multiple may be

characterized as a short-path or a peg-leg, for example, which may imply that a multiple may interfere with a primary reflection, or long-path, for example, where a multiple may appear as a separate event. As an example, seismic data may include evidence of an interbed multiple from bed interfaces, evidence of a multiple from a water interface (e.g., an interface of a base of water and rock or sediment beneath it) or evidence of a multiple from an air-water interface, etc.

[0062] As shown in Fig. 3, the acquired data 360 can include data associated with downgoing direct arrival waves, reflected upgoing primary waves, downgoing multiple reflected waves and reflected upgoing multiple reflected waves. The acquired data 360 is also shown along a time axis and a depth axis. As indicated, in a manner dependent at least in part on characteristics of media in the geologic environment 341, waves travel at velocities over distances such that relationships may exist between time and space. Thus, time information, as associated with sensed energy, may allow for understanding spatial relations of layers, interfaces, structures, etc. in a geologic environment.

[0063] Fig. 3 also shows a diagram 370 that illustrates various types of waves as including P, SV and SH waves. As an example, a P-wave may be an elastic body wave or sound wave in which particles oscillate in the direction the wave propagates. As an example, P-waves incident on an interface (e.g., at other than normal incidence, etc.) may produce reflected and transmitted S-waves (e.g., "converted" waves). As an example, an S-wave or shear wave may be an elastic body wave, for example, in which particles oscillate perpendicular to the direction in which the wave propagates. S-waves may be generated by a seismic energy sources (e.g., other than an air gun). As an example, S-waves may be converted to P-waves. S-waves tend to travel more slowly than P-waves and do not travel through fluids that do not support shear. In general, recording of S-waves involves use of one or more receivers operatively coupled to earth (e.g., capable of receiving shear forces with respect to time). As an example, interpretation of S-waves may allow for determination of rock properties such as fracture density and orientation, Poisson's ratio and rock type, for example, by crossplotting P-wave and S-wave velocities, and/or by other techniques.

[0064] Fig. 3 also shows an example of a technique 380 where equipment 381 such as a ship may tow an energy source and a string of sensors 383 at a depth

below the sea surface 382. In such an example, the energy source may emit energy at a time T0, a portion of that energy may be reflected from the seabed at a time T1 and a portion of that reflected energy may be received at the string of sensors 383 at a time T2. As an example, the equipment 381 may include one or more components such as one or more of the components of the system 250 of Fig. 2.

[0065] As mentioned with respect to the technique 340, a wave may be a primary or a wave may be a multiple. As shown in an enlarged view for the technique 380, the sea surface 382 may act to reflect waves such that sensors 385 of the string of sensors 383 may sense multiples as well as primaries. In particular, the sensors 385 may sense so-called sea surface multiples, which may be multiples from primaries or multiples of multiples (e.g., due to sub-seabed reflections, etc.).

[0066] As an example, each of the sensors 385 may sense energy of an upgoing wave at a time T2 where the upgoing wave reflects off the sea surface 382 at a time T3 and where the sensors may sense energy of a downgoing multiple reflected wave at a time T4 (see also the data 360). In such an example, sensing of the downgoing multiple reflected wave may be considered to be a form of noise that interferes with sensing of one or more upgoing waves. As an example, an approach that includes summing data acquired by a geophone and data acquired by a hydrophone may help to diminish noise associated with downgoing multiple reflected waves. Such an approach may be employed, for example, where sensors may be located proximate to a surface such as the sea surface 382 (e.g., arrival times T2 and T4 may be relatively close). As an example, the sea surface 382 or a water surface may be an interface between two media. For example, consider an air and water interface. As an example, due to differing media properties, sound waves may travel at about 1,500 m/s in water and at about 340 m/s in air. As an example, at an air and water interface, energy may be transmitted and reflected (e.g., consider an “impedance” mismatch).

[0067] As an example, each of the sensors 385 may include at least one geophone 386 and a hydrophone 387. As an example, a geophone may be a sensor configured for seismic acquisition, whether onshore and/or offshore, that can detect velocity produced by seismic waves and that can, for example, transform motion into electrical impulses. As an example, a geophone may be configured to detect motion in a single direction. As an example, a geophone may be configured to

detect motion in a vertical direction. As an example, three mutually orthogonal geophones may be used in combination to collect so-called 3C seismic data. As an example, a hydrophone may be a sensor configured for use in detecting seismic energy in the form of pressure changes under water during marine seismic acquisition. As an example, hydrophones may be positioned along a string or strings to form a streamer or streamers that may be towed by a seismic vessel (e.g., or deployed in a bore). Thus, in the example of Fig. 3, the at least one geophone 386 can provide for motion detection and the hydrophone 387 can provide for pressure detection. As an example, data 384 (e.g., analog and/or digital) may be transmitted via equipment, for example, for processing, etc.

[0068] As an example, a method may include analysis of hydrophone response and vertical geophone response, which may help to improve a PZ summation, for example, by reducing receiver ghost and/or free surface-multiple noise contamination (see, e.g., PZSUM algorithm, discussed further below). As an example, a ghost may be defined as a reflection of a wavefield as reflected from a water surface (e.g., water and air interface) that is located above a receiver, a source, etc. (e.g., a receiver ghost, a source ghost, etc.). As an example, a receiver may experience a delay between an upgoing wavefield and its downgoing ghost, which may depend on depth of the receiver.

[0069] As an example, a surface marine cable may be or include a buoyant assembly of electrical wires that connect sensors and that can relay seismic data to the recording seismic vessel. As an example, a multi-streamer vessel may tow more than one streamer cable to increase the amount of data acquired in one pass. As an example, a marine seismic vessel may be about 75 m long and travel about 5 knots, for example, while towing arrays of air guns and streamers containing sensors, which may be located, for example, about a few meters below the surface of the water. A so-called tail buoy may assist crew in location an end of a streamer. As an example, an air gun may be activated periodically, such as at about 25 m increments (e.g., about 10 second intervals) where the resulting sound wave travels into the Earth, which may be reflected back by one or more rock layers to sensors on a streamer, which may then be relayed as signals (e.g., data, information, etc.) to equipment on the tow vessel.

[0070] As an example, pressure data may be represented as “P” and velocity data may be represented as “Z”; noting, however, that the vertical component of a measured particle velocity vector may be denoted “V” and that “Z” may refer to a scaled, measured particle velocity. For example, in various equations presented herein, “V” represents a measured velocity and “Z” represents a scaling thereof.

[0071] As an example, a hydrophone may sense pressure information (e.g., P data) and a geophone may sense velocity information (e.g., V and/or Z data). As an example, a hydrophone may output signals, optionally as digital data, for example, for receipt by a system. As an example, a geophone may output signals, optionally as digital data, for example, for receipt by a system. As an example, the system 250 may receive P and V/Z data via one or more of the one or more network interfaces 260 and process such data, for example, via execution of instructions stored in the memory 258 by the processor 256. As an example, the system 250 may store raw and/or processed data in one or more of the one or more information storage devices 252.

[0072] Fig. 3 also shows an example of a scenario 390 where acquisition equipment 392 can emit energy from a source (e.g., a transmitter) and receiving reflected energy via one or more sensors (e.g., receivers) strung along an inline direction. As the region includes layers 393 and, for example, the geobody 395, energy emitted by a transmitter of the acquisition equipment 392 can reflect off the layers 393 and the geobody 395. Evidence of such reflections may be found in the acquired traces. As to the portion of a trace 396, energy received may be discretized by an analog-to-digital converter that operates at a sampling rate. For example, the acquisition equipment 392 may convert energy signals sensed by sensor Q to digital samples at a rate of one sample per approximately 4 ms. Given a speed of sound in a medium or media, a sample rate may be converted to an approximate distance. For example, the speed of sound in rock may be on the order of around 5 km per second. Thus, a sample time spacing of approximately 4 ms would correspond to a sample “depth” spacing of about 10 meters (e.g., assuming a path length from source to boundary and boundary to sensor). As an example, a trace may be about 4 seconds in duration; thus, for a sampling rate of one sample at about 4 ms intervals, such a trace would include about 1000 samples where latter acquired samples correspond to deeper reflection boundaries. If the 4 second trace

duration of the foregoing example is divided by two (e.g., to account for reflection), for a vertically aligned source and sensor, the deepest boundary depth may be estimated to be about 10 km (e.g., assuming a speed of sound of about 5 km per second).

[0073] Fig. 4 shows an example of a technique 440, examples of signals 462 associated with the technique 440, examples of interbed multiple reflections 450 and examples of signals 464 and data 466 associated with the interbed multiple reflections 450. As an example, the technique 440 may include emitting energy with respect to time where the energy may be represented in a frequency domain, for example, as a band of frequencies. In such an example, the emitted energy, with respect to time, may be a wavelet and, for example, referred to as a source wavelet which has a corresponding frequency spectrum (e.g., per a Fourier transform of the wavelet from a time domain to a frequency domain).

[0074] As an example, a geologic environment may include layers 441-1, 441-2 and 441-3 (e.g., rock layers, etc.) where an interface 445-1 exists between the layers 441-1 and 441-2 and where an interface 445-2 exists between the layers 441-2 and 441-3. As illustrated in Fig. 4, a wavelet may be first transmitted downward in the layer 441-1; be, in part, reflected upward by the interface 445-1 and transmitted upward in the layer 441-1; be, in part, transmitted through the interface 445-1 and transmitted downward in the layer 441-2; be, in part, reflected upward by the interface 445-2 (see, e.g., "i") and transmitted upward in the layer 441-2; and be, in part, transmitted through the interface 445-1 (see, e.g., "ii") and again transmitted in the layer 441-1. In such an example, signals (see, e.g., the signals 462) may be received as a result of wavelet reflection from the interface 445-1 and as a result of wavelet reflection from the interface 445-2. These signals may be shifted in time and in polarity such that addition of these signals results in a waveform that may be analyzed to derive some information as to one or more characteristics of the layer 441-2 (e.g., and/or one or more of the interfaces 445-1 and 445-2). For example, a Fourier transform of signals may provide information in a frequency domain that can be used to estimate a temporal thickness (e.g., Δzt) of the layer 441-2 (e.g., as related to acoustic impedance, reflectivity, etc.).

[0075] As to the data 466, as an example, they illustrate further transmissions of emitted energy, including transmissions associated with the interbed multiple

reflections 450. For example, while the technique 440 is illustrated with respect to interface related events i and ii, the data 466 further account for additional interface related events, denoted iii, that stem from the event ii. Specifically, as shown in Fig. 4, energy is reflected downward by the interface 445-1 where a portion of that energy is transmitted through the interface 445-2 as an interbed downgoing multiple and where another portion of that energy is reflected upward by the interface 445-2 as an interbed upgoing multiple. These portions of energy may be received by one or more receivers 444 (e.g., disposed in a well 443) as signals. These signals may be summed with other signals, for example, as explained with respect to the technique 440. For example, such interbed multiple signals may be received by one or more receivers over a period of time in a manner that acts to “sum” their amplitudes with amplitudes of other signals (see, e.g., illustration of signals 462 where interbed multiple signals are represented by a question mark “?”). In such an example, the additional interbed signals may interfere with an analysis that aims to determine one or more characteristics of the layer 441-2 (e.g., and/or one or more of the interfaces 445-1 and 445-2). For example, interbed multiple signals may interfere with identification of a layer, an interface, interfaces, etc. (e.g., consider an analysis that determines temporal thickness of a layer, etc.).

[0076] As an example, a method can include estimating structural dip in a subterranean environment based at least in part on seismic data. As an example, such a method can include estimating structural dip and modeling wave propagation based at least in part on the estimated structural dip. As an example, a method can include modeling a propagation dip field. As an example, a propagation dip field can be related to apparent structural dip, which may be measured from a seismic section of “stacked” data representing the likely position of subsurface reflectors at a target of interest.

[0077] As an example, a method can include receiving a gradient field derived from seismic data of a three-dimensional subterranean environment; determining a modified structure tensor based at least in part on the gradient field; and estimating a dip field based at least in part on the modified structure tensor. As an example, a method can include editing a dip field. As an example, an estimated dip field may be an edited dip field, for example, where the modified structure tensor is based at least in part on a horizon guided constraint that can mask dip in a region and/or, for

example, where the modified structure tensor introduces bias information, for example, to help overcome a scenario where there may be insufficient information as to structure in seismic data. As an example, a gradient field can be considered to include dip information. For example, a gradient field can include information from which a dip field may be estimated, edited, etc. As an example, a method can include determining one or more structure tensors, which may include one or more modified structure tensors, and estimating dip, editing dip, etc., based at least in part on one or more of such one or more structure tensors.

[0078] As an example, a framework can include a dip estimation tool that can be utilized to estimate a dip field, for example, from a seismic data stack (e.g., a seismic stack). As an example, such a dip field may be applied in a depth imaging workflow that can be part of a seismic interpretation workflow.

[0079] As an example, sedimentary rock may display transverse isotropy (TI) with a vertical symmetry axis (VTI), a general tilted symmetric axis (TTI) to seismic waves and/or one or more other types of isotropies, anisotropies, symmetries, asymmetries, etc.

[0080] As an example, a workflow can include inputting a dip field in a property population tool in a seismic velocity modeling plug-in, for example, to populate dip and azimuth of a TTI axis of symmetry of a TTI velocity model (e.g., or of another type of symmetry, asymmetry, model, etc.).

[0081] As an example, a framework such as the OMEGA™ framework (Schlumberger Limited, Houston, Texas) may be implemented to perform at least a portion of a method, a workflow, etc. For example, such a framework can extend geophysics data processing into reservoir modeling by integrating with a framework such as the PETREL® framework (e.g., seismic to simulation). As an example, Earth Model Building (EMB) tools may be utilized to enable a variety of depth imaging workflows, including model building, editing and updating, depth-tomography QC, residual moveout analysis, and volumetric common-image-point (CIP) pick QC. Such features, for example, in conjunction with the OMEGA™ framework's depth tomography and migration algorithms, can be utilized to generate images of a subsurface region or regions.

[0082] As an example, depth package features of a framework may provide algorithms that can allow for prestack and/or poststack depth migrations (e.g.,

isotropic (e.g., TTI) and/or anisotropic (e.g., VTI) velocity models), including, for example, Kirchhoff and wavefield extrapolation and may provide support for CIP tomography. As an example, a framework can include a depth package that may interact with seismic velocity modeling (e.g., of the same or a different framework).

[0083] As an example, a workflow can include inputting a dip field in the OMEGA™ framework. For example, consider inputting a dip field via a framework (e.g., via the seismic function module (SFM) CIP_DIFF in the OMEGA™ framework) to specify a ray shooting direction to calculate differential terms in residual migration equations via ray tracing.

[0084] As an example, a method can include inputting a dip field in the OMEGA™ framework SFM ZTOMO to shape a property update with steering filters.

[0085] As an example, a framework can include various modules that can intake dip estimation parameters, for example, via one or more dip estimation interfaces. As an example, a framework can provide one or more dip estimation outputs and, for example, one or more quality metrics (e.g., via dip estimation quality checks).

[0086] As an example, a method can include estimating a dip field based at least in part on computing a structure tensor. In such an example, the method may detect the dip field based at least in part on a structure tensor. As an example, a structure tensor can provide a local estimate of orientation of a 3D gradient of seismic data. For example, consider a method that includes computing a 3D gradient of a stacked image and that can then calculate the structure tensor from the stack gradient (e.g., gradient field), smoothed. Such a method can include decomposing data to detect a dominant direction of dip, for example, as a dip estimation (e.g., or dip detection).

[0087] As an example, in one or more regions, data may be of insufficient quality and/or include local variations in the stacked image of sufficient inconsistency that a dominant direction of dip is unclear. As an example, consider a scenario where two conflicting events with different dip at a single point exist. In such an example, or other example scenarios, a dip estimation algorithm may operate manually, semi-automatically and/or automatically to resize a smoothing window applied to the data to achieve a more stable or otherwise distinguishable direction of dip.

[0088] As an example, a window may be specified in terms of size, which may correspond to dimensions of a region in a subterranean environment. For example, a window may be specified in terms of meters. As an example, a larger window may “view” information on a larger scale; whereas, a smaller window may “view” information on a smaller scale. As an example, a larger window may provide for smoothing over a scale that is larger than smoothing provided by a smaller window. As an example, seismic data may be specified according to a resolution. As an example, a smoothing window may be selected based at least in part on a resolution of seismic data (e.g., or data derived at least in part from seismic data).

[0089] Fig. 5 shows an example of a method 500 that includes a reception block 510 for receiving an input stack volume (e.g., a seismic volume of seismic cube, which may be denoted $f(x, y, z)$), a calculation block 520 for calculating a gradient of the stack volume (e.g., a gradient field of the stack volume), a calculation block 530 for calculating the structure tensor and a determination block 540 for determining one or more dips (e.g., estimated dip or dips), which may be one or more dips of a dip field (e.g., an estimated dip field, etc.).

[0090] The method 500 is shown in Fig. 5 in association with various computer-readable media (CRM) blocks 511, 521, 531 and 541. Such blocks generally include instructions suitable for execution by one or more processors (or cores) to instruct a computing device or system to perform one or more actions. While various blocks are shown, a single medium may be configured with instructions to allow for, at least in part, performance of various actions of the method 500. As an example, a computer-readable medium (CRM) may be a computer-readable storage medium. As an example, blocks may be provided as one or more modules, for example, such as the one or more modules 270 of Fig. 2 and/or instructions that can be stored in memory (e.g., the memory 258 of the system 250 of Fig. 2).

[0091] In the example of Fig. 5, the calculation block 520 can include calculating the gradient of the stack volume (e.g., a gradient field of the stack volume) where the gradient of the stack is a vector whose components are the partial derivations of $f(x, y, z)$:

$$\bar{\nabla}f = \frac{\partial f}{\partial x}\bar{i} + \frac{\partial f}{\partial y}\bar{j} + \frac{\partial f}{\partial z}\bar{k}$$

[0092] In such an example, the gradient can point in a direction of the greatest rate of increase of the function $f(x,y,z)$ where, for example, its magnitude is the instantaneous rate of change of the function in that direction.

[0093] As an example, the calculation block 530 can include calculating the structure tensor from the stack gradient (e.g., from the gradient field of the stack volume). For example, the structure tensor, which may be referred to as the second-moment matrix, can be a 3 x 3 matrix (e.g., for three dimensions such as x , y and z) derived from the gradient of $f(x,y,z)$. As an example, a structure tensor can “summarize” the dominant directions of the gradient in a specified neighborhood of a point and, for example, the degree to which those directions may be coherent.

[0094] As an example, the calculation block 530 can include using one or more structure tensor window length parameters to calculate the structure tensor. For example, consider parameters that specify a window length of about four times the input sampling. As an example, a method can include tailoring one or more parameter values, for example, to increase accuracy of dip estimations in one or more areas of interest.

[0095] As an example, the determination block 540 may include using Eigen theory. For example, consider a method that includes calculating at least one eigenvalue. As an example, consider a method that includes calculating two eigenvalues and assigning these two eigenvalues as dominant dips (λ_1 , λ_2). In such an example, a method can include calculating an initial dip quality (IQ), for example, using a formula such as:

$$IQ = \sqrt{\frac{(\lambda_1 - \lambda_2)}{(\lambda_1 + \lambda_2)}}$$

[0096] As an example, a method can include determining the length of a smoothing filter (e.g., a smoothing window, etc.) at one or more locations. For example, consider a smoothing filter that is a 3D Gaussian filter, which may be, for example, defined as three 1D Gaussian filter in cascade (e.g., the first is a filter in the x direction, the second is in the y direction and the third is in the z direction). As

an example, consider a 1D Gaussian filter where L is the filter length and where the filter can be set forth via the formula:

$$g(x) = e^{-\frac{x^2}{2\sigma^2}}$$

where $\sigma = \frac{L}{6}$.

[0097] As an example, a method can include smoothing a structure tensor, for example, using a self-adaptive Gaussian filter or other type of filter.

[0098] As an example, a method can include using Eigen theory to calculate two dominant dips (λ_1 , λ_2) and can include setting an estimated dip for a region to be equal to the dominant dip (λ_1). In such an example, quality (e.g., IQ) may be determined where, if the quality is close to one, confidence exists that the dip is a good estimate, however, if the quality is close to zero, the estimated dip can be indicative of conflicting dips.

[0099] As an example, in a three-dimensional (3D) space, eigenvalues λ_1 , λ_2 , and λ_3 of a structure tensor and corresponding eigenvectors e_1 , e_2 , and e_3 can summarize the distribution of gradient directions within a neighborhood of a point p defined, for example, by a window w that may be centered on the point p . Such information may be visualized as an ellipsoid whose semi-axes can be equal to the eigenvalues and directed along their corresponding eigenvectors. Such an approach can provide an ellipsoidal representation of a 3D structure tensor. As an example, if an ellipsoid is stretched along one axis, like a cigar (e.g., $\lambda_1 \gg \lambda_2$ and λ_3), it can mean that the gradient in the window w is predominantly aligned with the direction of the eigenvector e_1 , so that the isosurfaces of a function I tend to be flat and perpendicular to that vector. As an example, such a scenario can arise where p lies on a thin plate-like feature or, for example, on a smooth boundary between two regions with contrasting values.

[00100] As explained above, a structure tensor may be utilized in a dip estimation process (e.g., dip field estimation, etc.). As an example, a structure tensor may be utilized to analyze data such as seismic data or processed seismic data (e.g., a gradient field, etc.). As an example, a structure tensor can be utilized to

extract information about orientation from data, which may be, for example, seismic data, processed seismic data, images, etc. As an example, consider a method that includes applying a structure tensor based approach to an image of a seismic stack to extract orientation or dip of spatially coherent reflection events.

[00101] As an example, a structure tensor approach may encounter one or more quality or other issues where coherent noise exists in seismic data, processed seismic data, etc. As an example, where poor reflectivity exists, a structure tensor approach may encounter one or more quality issues as to estimation of structural dip.

[00102] As an example, a method can include masking effects of coherent noise and/or providing additional information about expected structure in one or more regions of interest of a subterranean environment. For example, such a method can be a structure tensor based method where a masking approach may be implemented or, for example, such a method can be a structure tensor based method where a supplementation or biasing approach may be implemented (e.g., to provide additional information). As an example, a workflow can include masking and biasing in one or more structure tensor based approaches. As an example, such approaches may be considered modified structure tensor approaches that, for example, modify a gradient field.

[00103] Fig. 6 shows an example of an environment 610 where an object 615 is disposed within one or more layers 617 of material (e.g., one or more layers of sediment, etc.) and where a surface of the object 615 has a local orientation at various points with respect to an orientation of the one or more layers 617. As an example, the environment 610 can be a subterranean environment where the object 615 is a body such as a geobody or other structure within the subterranean environment. While Fig. 6 shows cross-sectional views, the environment 610 and the object 615 and the layers 617 can be three-dimensional (see, e.g., Fig. 9).

[00104] As mentioned, a method can include masking and/or biasing. With respect to the example of Fig. 6, consider a method that includes masking as illustrated in an approximate graphic 630 and a method that includes biasing as illustrated in an approximate graphic 650.

[00105] As to various notations that appear in Fig. 6, consider the following definitions. As to $\nabla I(p)$, this is gradient of a function that can be defined in a three-

dimensional Cartesian coordinate system, with respect to a point p , as follows where I is a function of three variables (x , y and z) and where the subscripts x , y and z indicate derivatives of that function.

$$\nabla I(p) := \begin{bmatrix} I(p)_x \\ I(p)_y \\ I(p)_z \end{bmatrix}$$

[00106] The transpose of the gradient of the function can be denoted as $\nabla I'(p)$ and may be represented as follows:

$$\nabla I'(p) := [I(p)_x \quad I(p)_y \quad I(p)_z]$$

[00107] As to the structure tensor, it may be defined as follows:

$$S(p) = \int w(p-s) \nabla I(s) \nabla I'(s) ds$$

[00108] In the foregoing equation, the structure tensor at point p is defined with respect to a support, s (e.g., a compact support). As an example, a support may be a distance from a point. As an example, the support s may be a radius or other distance that can be measured from the point p . As an example, a support may be symmetric or asymmetric. As an example, a support may be a sphere, an ellipse, a box, etc.

[00109] In the foregoing equation, as to w , it can represent a weight that can be applied about the point p in a manner that depends on the support s .

[00110] Referring again to Fig. 6, as shown, the gradient of the function, $\nabla I(p)$, is shown as being substantially outwardly normal to the surface of the object 615 while another representation, $\nabla I'(p)$, is shown as being substantially normal to several of the layers 617 that interface with the object 615 in the environment 610.

[00111] In the context of seismic data, which may be processed seismic data (e.g., seismic attribute data, etc.), consider a 3D seismic stack section, with amplitude at a point $p = (x, y, z) \in \mathbb{R}^3$ given by the function $I(p)$. In such an example, the gradient and the transpose of the gradient may be defined as set forth above.

[00112] As to the structure tensor, as noted, the formulation includes a weight, which can be defined as a weighting function $w(p)$, for example, centered at $p = 0$ with compact support, s (see above). As an example, such a function can be a windowing function or window function (e.g., as associated with support about a point, etc.).

[00113] In Fig. 6, the graphic for the masking approach 630 and the graphic for the biasing approach 650 represent different manners of processing based at least in part on a structure tensor, which can be a modified structure tensor (e.g., modified for the masking approach or modified for the biasing approach).

[00114] As an example, consider defining two forms of a projected structure tensor, where one form can be used to help reduce influence of unwanted structure from on a structure tensor. In such an example, a projection can be defined where $\alpha(p)$ is a weighting function of p and where $\nabla I(p)$ denotes a vector field that describes the gradient of unwanted structure, which may be zero where no such structure is present. In the example of Fig. 6, the “unwanted structure” may be that of the object 615 (see, e.g., arrows representing $\nabla I(p)$ in Fig. 6).

[00115] As an example, consider the masking approach graphic 630 where influence of information associated with the object 615 can be reduced (e.g., at least in part removed, etc.). In such an example, a 3x1 vector for $\nabla I(p)$ may be represented as v . In such an example, $\alpha(p)$ may be considered to be acting on v to reduce the influence of $\nabla I(p)$. Such an approach may be applied, for example, where conflicting dips exist (see, e.g., line and arc in Fig. 6) and where one of the dips (e.g., the arc) is to be subtracted (e.g., reduced).

[00116] In view of the foregoing, consider the following formulations:

$$\begin{aligned} \tilde{S}(p) &= S(p) - \alpha(p) \nabla I(p) \nabla I'(p) \\ \alpha(p) &\in [0,1] \\ \nabla I(p) &\in \mathbb{R}^3 \end{aligned}$$

[00117] Given the foregoing formulations, the resulting projected structure tensor (e.g., a type of modified structure tensor) can be set forth as follows:

$$\tilde{S}(p) = \int w(p-s) \nabla I(s) \nabla I'(s) ds$$

[00118] As indicated in the graphic 630, $\tilde{S}(p)$, can remove at least some of the influence of $\nabla I(p)$, which as shown in the scenario 610 is associated with the object 615 as it resides at least in part within the layers 617 which can be reflective interfaces (e.g., reflectors). Such an approach can be referred to as masking because the influence of the object 615 within the layers 617 (e.g., reflective interfaces) in the environment 610 may be masked while preserving information associated with the layers 617 (e.g., reflective interfaces). As an example, the layers 617 can be sedimentary layers where the object 615 forms interfaces with one or more of the layers 617. As an example, where dip associated with the layers 617 is to be estimated, the object 615 may be an unwanted structure where information within seismic data can interfere with estimation of dip of one or more of the layers 617.

[00119] As to the biasing approach associated with the graphic 650, another formulation can be used to introduce a bias to the structure tensor computation. To define this form of the structure tensor, a bias function can be introduced, for example, using various conventions as above. However, such biasing as shown in Fig. 6 can act to reduce influence of $\nabla I(p)$ (e.g., remove at least some information thereof), which may be represented as v .

[00120] As an example, consider the following formulations that can be used to define a biased structure tensor (e.g., another type of modified structure tensor).

$$\mathbb{B}(v) = \alpha(p) \nabla I(p) + (1 - \alpha(p))(\nabla I(p) \nabla I(p)')v$$

$$\tilde{S}_{\mathbb{B}}(p) = \int w(p-s) (\mathbb{B} \nabla I(s) \nabla I'(s) \mathbb{B}') ds$$

[00121] As an example, such an approach can be used to introduce structure (e.g., bias) where a consistent direction may not present on input. As an example, such an approach can be utilized to effectively introduce information about an expected dip or dips (e.g., by biasing information). As an example, a biasing approach may be utilized to analyze dip as associated with an object such as, for example, the object 615 of Fig. 6 (e.g., an object in a subterranean environment).

[00122] As an example, a system can include a display to which information can be rendered. For example, a system can include processor-executable instructions that cause rendering of one or more graphical user interfaces (GUIs) to a display where such a GUI or GUIs allow for selection of an option or options to determine a modified structure tensor or modified structure tensors as part of a workflow.

[00123] Fig. 7 shows an example of a graphical user interface (GUI) 700 that can be part of a framework and, for example, rendered via a computing device to a display, which may be a touchscreen display. For example, a framework can be implemented via a computing device, a computing system, etc., where instructions stored in memory can be executed by one or more processors (e.g., CPU, GPU, etc.) to cause rendering of information to a display. As an example, a GUI can include one or more graphical controls that can be actuated via an input mechanism or input mechanisms (e.g., touchscreen, stylus, mouse, keyboard, touchpad, voice, etc.). As an example, a GUI can include various fields that can be used to specify information, which may be values of parameters, names of files, etc. As an example, a GUI can include a graphical control to select an option of a plurality of options. As an example, a GUI can include a control buttons such as an “Apply” button, an “OK” button, a “Cancel” button, etc.

[00124] As an example, a framework may be operatively coupled to another framework such as, for example, the PETREL® framework (e.g., for seismic to simulation workflows, etc.). As an example, the GUI 700 may be part of a framework such as, for example, the OMEGA™ framework.

[00125] In the example of Fig. 7, the GUI 700 can be rendered to a display as part of a workflow that includes dip estimation. In such an example, the GUI 700 can include an input section 710, an output section 720, a parameters section a horizon guided parameters section 740, a type section 750 and a quality control (QC) section 760.

[00126] As an example, seismic data may be organized with respect to inline, crossline (“Xline”) and depth. Inline, crossline and depth may correspond to x, y, and z coordinate of a Cartesian or other type of coordinate system. As an example, seismic data may be associated with a sample rate. For example, consider a

sample rate of 25 meters by 25 meters by 6 meters corresponding to inline, crossline and depth, respectively.

[00127] In the example of Fig. 7, the GUI 700 includes a graphical control 754 to select a mask option and a graphical control 758 to select a bias option. Such options can correspond to processes such as a process associated with the graphics 630 and 650, respectively. As an example, a workflow can run one option and then run another option.

[00128] As mentioned, quality control can allow for assessing estimated results for dip (e.g., a dip field, etc.). As an example, the GUI 700 may be utilized to assess quality of an output dip field and/or one or more other outputs.

[00129] Fig. 8 shows an example of a GUI 810 that can include representations of information with respect to an environment where such representations can include representations that indicate quality of information at various locations in the environment. In the example GUI 810, the environment is shown as including curved structures, as may be seen in a cross-section with respect to inline or crossline direction and depth and as may be seen as rising above an inline and crossline plane, for which an enlarged portion 830 is also shown in Fig. 8.

[00130] In the example of Fig. 8, the information pertains to two attributes for dip quality control (QC), an ellipsoid attribute and a line attribute. Such information can be overlaid on a stack intersection, as shown in Fig. 8. In the example of Fig. 8, the ellipsoid attribute provides a 3D representation of the true dip's orientation at a given location and the line attribute provides a 2D representation of the apparent dip's orientation for a given intersection and at a given location.

[00131] As an example, ellipsoid and line attributes may be rendered to a display at dip field resolution where, for example, their size is fitted in a cell which is defined by the dip field resolution. As an example, a graphical control can allow a user to access settings of these two attributes and allow a user to then set the appropriate parameters (e.g., for visualization, etc.).

[00132] As an example, a framework can provide for displaying a 3D stack in a 3D window, which may appear as in the GUI 810. As an example, a workflow can include overlaying a line object (e.g., line attribute) on an inline stack, overlaying a line object (e.g., line attribute) on a crossline stack and overlaying an ellipsoid object (e.g., ellipsoid attribute) on a depth slice. For example, in the GUI 810, the depth

slice in the inline and crossline plane illustrates ellipsoids (see also the enlarged portion 830) while lines are illustrated in the cross-section that bounds an edge of the plane.

[00133] As an example, a scale may be rendered to a display (e.g., as part of the GUI 810, etc.). As an example, a scale may indicate a color, shading or other scheme as to values of information represented in a GUI, etc.

[00134] As an example, dip quality can represent consistency of a dip field to a seismic, for example, using a range where 0 is least consistent and where 1 is most consistent. As an example, inline dip can be visualized as the projection of the dip/azimuth (vector) on the inline intersection. As an example, the unit of measure can be in degrees. As an example, a convention can be utilized where dip is positive dipping down as the crossline number increases on an inline intersection. As an example, crossline dip can be visualized as the projection of the dip/azimuth (vector) on the crossline intersection. As an example, the unit of measure can be in degrees. As an example, a convention can be utilized where dip is positive dipping down as the inline number increases on a cross line intersection. As an example, a method can include generating color tables for dip, azimuth and quality to visualize inline, dip, crossline dip, and dip quality.

[00135] As an example, QC can allow for detection of one or more artifacts that may exist in a volume. For example, consider artifacts such as one or more of acquisition footprints, stripes, etc. As an example, QC can allow for detection of anomalous dip and/or one or more other conditions.

[00136] As an example, a QC workflow can include further processing of seismic data, etc. For example, a workflow may include implementing one or more of a masking technique and/or a biasing technique to improve a dip estimate (e.g., to improve an estimated dip field, etc.).

[00137] As an example, a method can include calculating a structure tensor where the calculating includes imposing one or more prior assumptions about structural dip.

[00138] As an example, a method can include calculating a structure tensor from an estimate of an image gradient. In such an example, the method can include modifying the estimated gradient in one or more manners. For example, one manner can include projecting a pointwise representation of gradient onto the

complement of the dip of coherent noise. Such an approach can effectively make the structure tensor estimation procedure “blind” to dips related to coherent noise. Such an approach may be referred to, for example, as a masking approach.

[00139] As an example, coherent noise may appear as features that span multiple layers (e.g., rock layers). As an example, coherent noise may appear in a medium other than rock. For example, at a sea floor, coherent noise may appear in water adjacent to a sea floor and water interface.

[00140] As an example of another manner, it may include biasing a pointwise representation of the gradient with additional information about a background dip field, for example, by introducing contributions from an expected dip. Such an approach may be referred to, for example, as a biasing approach.

[00141] As an example, one or more approaches can allow a structure tensor estimation process to incorporate expectations about a dip field, for example, by removing energy from irrelevant structure or, for example, by adding information about expected structure.

[00142] As an example, a method can include estimating a dip field and optionally editing the estimated dip field, for example, using one or more horizon guided constraints. For example, consider a constraint that aims to reduce the influence of dip detected in an area of data based on a structure such as a salt flank. In such an example, the reduction of the influence of dip in the area associated with the structure may facilitate ray tracing in a sediment zone. As an example, a method can address a scenario where there may be insufficient structure information in seismic data for purposes of dip estimation. In such an example, a method can include biasing in a manner that effectively adds information.

[00143] Fig. 9 shows an example of a method 900 that includes a reception block 910 for receiving a gradient field derived from seismic data of a three-dimensional subterranean environment; a determination block 920 for determining a modified structure tensor based at least in part on the gradient field; and an estimation block 930 for estimating a dip field based at least in part on the modified structure tensor. As an example, such a method may include receiving seismic data of a three-dimensional subterranean environment and deriving a gradient field from at least a portion of such seismic data, which may be, for example, seismic attribute

data, etc. As an example, a method may include acquiring seismic data via a field operation that uses seismic data acquisition equipment.

[00144] In the example of Fig. 9, a block 924 is shown for a masking option and a block 928 is shown for a biasing option. For example, a masking option can be utilized to modify the gradient field to determine a modified structure tensor and/or a biasing option can be utilized to modify the gradient field to determine a modified structure tensor.

[00145] The method 900 is shown in Fig. 9 in association with various computer-readable media (CRM) blocks 911, 921, 925, 929 and 931. Such blocks generally include instructions suitable for execution by one or more processors (or cores) to instruct a computing device or system to perform one or more actions. While various blocks are shown, a single medium may be configured with instructions to allow for, at least in part, performance of various actions of the method 900. As an example, a computer-readable medium (CRM) may be a computer-readable storage medium. As an example, blocks may be provided as one or more modules, for example, such as the one or more modules 270 of Fig. 2 and/or instructions that can be stored in memory (e.g., the memory 258 of the system 250 of Fig. 2).

[00146] As an example, the method 900 can include rendering information to a display. For example, consider information such as the information of the graphical user interface 810 of Fig. 8. As an example, information may include dip field information, which may optionally be displayed in 2D and/or 3D views. As an example, a method can include building or editing a model of a subterranean environment based at least in part on an estimated dip field. As an example, a method can be iterative where, for example, various portions of data of a subterranean environment may be refined via one or more approaches, which may optionally include determining a modified structure tensor or modified structure tensors.

[00147] Fig. 10 shows examples of some different types of structural environments or regions including an approximately zero dip region 1010, a low dip region 1020, a moderate dip region 1030, a non-plunging fold region 1040, a plunging fold region 1050, a doubly plunging fold region 1060 and an approximately circular dome region 1070. The diagrams of Fig. 10 are generalized to illustrate

some examples of different types of categories of geologic bulk curvature where, for example, transverse (T) and longitudinal (L) can be mutually perpendicular directions. As an example, a T-direction may be defined to be a cross-section (e.g., through a borehole) that exhibits the greatest structural change and an L-direction may be the direction of cross-section that shows the least structural change.

[00148] In the examples of Fig. 10, one or more of the environments or regions can include one or more objects. For example, consider one or more geobodies being present, which may give rise to conflicting dips, etc. in one or more regions. As an example, consider a scenario or scenarios where an object such as, for example, the object 615 of Fig. 6, is present in one or more of the regions 1010 to 1070 of Fig. 10. As an example, a masking and/or a biasing approach may be implemented for such a scenario or scenarios as part of a dip workflow, etc. (e.g., to estimate dip, to edit dip, etc.).

[00149] As an example, structural bulk curvature can imply that a bed of a structure shares at least some curvature properties and/or regularities with one or more other beds (e.g., on a common structure). As an example, regularities may be classified according to a manner in which angle of dip varies as a function of azimuth of dip. The diagrams of Fig. 10 are some examples of how a structural setting can be described by a type of structural bulk curvature. As an example, structural bulk curvature and related transverse and longitudinal structural directions can allow for determining structural dip (e.g., true structural dip), determining bearing and plunge of crestal and trough lines of folds, determining the strike and dip of crestal, axial and inflection planes of folds, determining the strike and direction of dip of dip-slip faults. Determinations as to such three-dimensional geometries of a subterranean environment can be utilized to assess the subterranean environment and, for example, facilitate planning, execution of a production plan (e.g., drilling, stimulation, etc.) and production.

[00150] As an example, a method can include receiving data from one or more seismic surveys and optionally receiving data from one or more boreholes. As an example, a method can include performing analyses on seismic survey data and optionally performing analyses on borehole data. As an example, a workflow may include interpreting seismic survey data, optionally with aid of borehole data (e.g., borehole imagery data, borehole lithology data, etc.).

[00151] As an example, dip or dip information may be conveyed in one or more forms. For example, consider the graphical user interface (GUI) 810 of Fig. 8 where information may be presented via a rendering that shows three dimensions (e.g., x, y and z) and 2D and/or 3D structural representations on a substantially two-dimensional display screen. As an example, where holographic or 3D display or projection technology is provided, a rendering may create a three-dimensional rendering or otherwise effectuate a three-dimensional rendering (e.g., consider use of “3D” glasses, virtual reality goggles, etc.) of structural representations in 2D and/or 3D. As an example, various plot forms may be utilized to convey dip or dip information. For example, consider an angle-of-dip versus depth plot.

[00152] As an example, a method may be implemented as a plug-in of a framework. For example, consider a method implemented as processor-executable instructions stored in memory as a dip estimation plug-in of a framework such as, for example, the PETREL® framework. As an example, a method or workflow can include model building, model editing, etc. For example, a model may be built or edited based at least in part on one or more dip estimations. Such a model may be a reservoir model (e.g., a model of grid cells, etc., suitable for simulating one or more types of physical phenomena). As an example, a reservoir model may be suitable for use by a reservoir simulator (e.g., a computerized reservoir simulation system).

[00153] As an example, a method can include editing a dip field after dip estimation, for example, using one or more horizon guided constraints that can reduce certain dip detected in an area of the data, for example, based on a structure such as a salt flank or other geobody, etc. In such an example, reduction of certain dip can facilitate ray tracing, for example, in a sediment zone. As an example, a method may be employed to address insufficient structure in the seismic data to estimate dip. As an example, a method may employ a masking technique and/or a biasing technique.

[00154] As an example, a method can include receiving a gradient field derived from seismic data of a three-dimensional subterranean environment; determining a modified structure tensor based at least in part on the gradient field; and estimating a dip field based at least in part on the modified structure tensor. In such an example, determining a modified structure tensor can include modifying the gradient field. For

example, consider a method that includes modifying the gradient field at least in part by imposing a horizon guided constraint.

[00155] As an example, a method can include modifying a gradient field at least in part by projecting a pointwise representation of the gradient field onto a complement of dip of coherent noise. For example, consider a scenario where the dip of coherent noise is associated with a subterranean object in a sediment zone of the three-dimensional subterranean environment.

[00156] As an example, a method can include determining a modified structure tensor at least in part via masking information associated with a subterranean object in a sediment zone of a three-dimensional subterranean environment.

[00157] As an example, a method can include receiving a gradient field derived from seismic data of a three-dimensional subterranean environment; determining a modified structure tensor based at least in part on the gradient field; and estimating a dip field based at least in part on the modified structure tensor. In such an example, determining a modified structure tensor can include modifying the gradient field. For example, consider a method that includes modifying the gradient field at least in part by biasing the gradient field. In such an example, biasing the gradient field can include introducing contributions from one or more expected dips associated with expected structure in the three-dimensional subterranean environment.

[00158] As an example, a method can include receiving a gradient field derived from seismic data of a three-dimensional subterranean environment; determining a modified structure tensor based at least in part on the gradient field; and estimating a dip field based at least in part on the modified structure tensor. In such an example, determining a modified structure tensor can include determining a projected structure tensor. For example, consider a method where the projected structure tensor is defined based at least in part by a vector field that describes the gradient of a structure in the three-dimensional subterranean environment. In such an example, the projected structure tensor can mask the structure in the three-dimensional subterranean environment or, for example, the projected structure tensor can be biased by the structure in the three-dimensional subterranean environment.

[00159] As an example, a method can include receiving a gradient field derived from seismic data of a three-dimensional subterranean environment; determining a modified structure tensor based at least in part on the gradient field; and estimating a

dip field based at least in part on the modified structure tensor where determining a modified structure tensor includes imposing a constraint that reduces dip detected in a region that includes a subterranean object in a sediment zone of the three-dimensional subterranean environment. In such an example, the subterranean object may be a geobody or other type of object. As an example, a subterranean object may appear within sediment where the sediment may include layers of sediment that may be defined by dip and where the subterranean object may be defined by dip. As an example, the presence of a subterranean object in layers of sediment may act to cause dipping of one or more of such layers, which may be, for example, layers of sediment. As an example, such dipping may be local in a neighborhood of the subterranean object and may, for example, gradually diminish (e.g., as to the “influence” of the shape of the subterranean object on other subterranean material, etc.).

[00160] As an example, a method can include receiving a gradient field derived from seismic data of a three-dimensional subterranean environment; determining a modified structure tensor based at least in part on the gradient field; and estimating a dip field based at least in part on the modified structure tensor where such estimating may be based at least in part on performing ray tracing. For example, a method can include, based at least in part on a modified structure tensor, performing ray tracing in a sediment zone. In such an example, the method may include masking and/or biasing prior to performing ray tracing.

[00161] As an example, a system can include a processor; memory operatively coupled to the processor; and processor-executable instructions stored in the memory to instruct the system where the instructions include instructions to receive a gradient field derived from seismic data of a three-dimensional subterranean environment; determine a modified structure tensor based at least in part on the gradient field; and estimate a dip field based at least in part on the modified structure tensor. In such an example, the instructions to determine a modified structure tensor can include instructions to bias the gradient field and/or instructions to mask information associated with a subterranean object in the three-dimensional subterranean environment.

[00162] As an example, one or more computer-readable storage media can include computer-executable instructions to instruct a computer where the

instructions include instructions to: receive a gradient field derived from seismic data of a three-dimensional subterranean environment; determine a modified structure tensor based at least in part on the gradient field; and estimate a dip field based at least in part on the modified structure tensor. In such an example, the instructions to determine a modified structure tensor can include instructions to bias the gradient field and/or can include instructions to mask information associated with a subterranean object in the three-dimensional subterranean environment.

[00163] Fig. 11 shows components of an example of a computing system 1100 and an example of a networked system 1110. The system 1100 includes one or more processors 1102, memory and/or storage components 1104, one or more input and/or output devices 1106 and a bus 1108. In an example embodiment, instructions may be stored in one or more computer-readable media (e.g., memory/storage components 1104). Such instructions may be read by one or more processors (e.g., the processor(s) 1102) via a communication bus (e.g., the bus 1108), which may be wired or wireless. The one or more processors may execute such instructions to implement (wholly or in part) one or more attributes (e.g., as part of a method). A user may view output from and interact with a process via an I/O device (e.g., the device 1106). In an example embodiment, a computer-readable medium may be a storage component such as a physical memory storage device, for example, a chip, a chip on a package, a memory card, etc. (e.g., a computer-readable storage medium).

[00164] In an example embodiment, components may be distributed, such as in the network system 1110. The network system 1110 includes components 1122-1, 1122-2, 1122-3, . . . 1122-N. For example, the components 1122-1 may include the processor(s) 1102 while the component(s) 1122-3 may include memory accessible by the processor(s) 1102. Further, the component(s) 1102-2 may include an I/O device for display and optionally interaction with a method. The network may be or include the Internet, an intranet, a cellular network, a satellite network, etc.

[00165] As an example, a device may be a mobile device that includes one or more network interfaces for communication of information. For example, a mobile device may include a wireless network interface (e.g., operable via IEEE 802.11, ETSI GSM, BLUETOOTH®, satellite, etc.). As an example, a mobile device may include components such as a main processor, memory, a display, display graphics

circuitry (e.g., optionally including touch and gesture circuitry), a SIM slot, audio/video circuitry, motion processing circuitry (e.g., accelerometer, gyroscope), wireless LAN circuitry, smart card circuitry, transmitter circuitry, GPS circuitry, and a battery. As an example, a mobile device may be configured as a cell phone, a tablet, etc. As an example, a method may be implemented (e.g., wholly or in part) using a mobile device. As an example, a system may include one or more mobile devices.

[00166] As an example, a system may be a distributed environment, for example, a so-called “cloud” environment where various devices, components, etc. interact for purposes of data storage, communications, computing, etc. As an example, a device or a system may include one or more components for communication of information via one or more of the Internet (e.g., where communication occurs via one or more Internet protocols), a cellular network, a satellite network, etc. As an example, a method may be implemented in a distributed environment (e.g., wholly or in part as a cloud-based service).

[00167] As an example, information may be input from a display (e.g., consider a touchscreen), output to a display or both. As an example, information may be output to a projector, a laser device, a printer, etc. such that the information may be viewed. As an example, information may be output stereographically or holographically. As to a printer, consider a 2D or a 3D printer. As an example, a 3D printer may include one or more substances that can be output to construct a 3D object. For example, data may be provided to a 3D printer to construct a 3D representation of a subterranean formation. As an example, layers may be constructed in 3D (e.g., horizons, etc.), geobodies constructed in 3D, etc. As an example, holes, fractures, etc., may be constructed in 3D (e.g., as positive structures, as negative structures, etc.).

[00168] Although only a few example embodiments have been described in detail above, those skilled in the art will readily appreciate that many modifications are possible in the example embodiments. Accordingly, all such modifications are intended to be included within the scope of this disclosure as defined in the following claims. In the claims, means-plus-function clauses are intended to cover the structures described herein as performing the recited function and not only structural equivalents, but also equivalent structures. Thus, although a nail and a screw may

not be structural equivalents in that a nail employs a cylindrical surface to secure wooden parts together, whereas a screw employs a helical surface, in the environment of fastening wooden parts, a nail and a screw may be equivalent structures. It is the express intention of the applicant not to invoke 35 U.S.C. § 112, paragraph 6 for any limitations of any of the claims herein, except for those in which the claim expressly uses the words “means for” together with an associated function.

CLAIMS

What is claimed is:

1. A method comprising:
 - receiving a gradient field derived from seismic data of a three-dimensional subterranean environment;
 - determining a modified structure tensor based at least in part on the gradient field; and
 - estimating a dip field based at least in part on the modified structure tensor.
2. The method of claim 1 wherein determining a modified structure tensor comprises modifying the gradient field.
3. The method of claim 2 wherein modifying the gradient field comprises imposing a horizon guided constraint.
4. The method of claim 2 wherein modifying the gradient field comprises projecting a pointwise representation of the gradient field onto a complement of dip of coherent noise.
5. The method of claim 4 wherein the dip of coherent noise is associated with a subterranean object in a sediment zone of the three-dimensional subterranean environment.
6. The method of claim 1 wherein determining a modified structure tensor comprises masking information associated with a subterranean object in a sediment zone of the three-dimensional subterranean environment.
7. The method of claim 2 wherein modifying the gradient field comprises biasing the gradient field.

8. The method of claim 7 wherein biasing the gradient field comprises introducing contributions from one or more expected dips associated with expected structure in the three-dimensional subterranean environment.
9. The method of claim 1 wherein determining a modified structure tensor comprises determining a projected structure tensor.
10. The method of claim 9 wherein the projected structure tensor is defined based at least in part by a vector field that describes the gradient of a structure in the three-dimensional subterranean environment.
11. The method of claim 10 wherein the projected structure tensor masks the structure in the three-dimensional subterranean environment.
12. The method of claim 10 wherein the projected structure tensor is biased by the structure in the three-dimensional subterranean environment.
13. The method of claim 1 wherein determining a modified structure tensor comprises imposing a constraint that reduces dip detected in a region that comprises a subterranean object in a sediment zone of the three-dimensional subterranean environment.
14. The method of claim 13 comprising, based at least in part on the modified structure tensor, performing ray tracing in the sediment zone.
15. A system comprising:
 - a processor;
 - memory operatively coupled to the processor; and
 - processor-executable instructions stored in the memory to instruct the system, the instructions comprising instructions to
 - receive a gradient field derived from seismic data of a three-dimensional subterranean environment;

determine a modified structure tensor based at least in part on the gradient field; and

estimate a dip field based at least in part on the modified structure tensor.

16. The system of claim 15 wherein the instructions to determine a modified structure tensor comprises instructions to bias the gradient field.

17. The system of claim 15 wherein the instructions to determine a modified structure tensor comprises instructions to mask information associated with a subterranean object in the three-dimensional subterranean environment.

18. One or more computer-readable storage media comprising computer-executable instructions to instruct a computer, the instructions comprising instructions to:

receive a gradient field derived from seismic data of a three-dimensional subterranean environment;

determine a modified structure tensor based at least in part on the gradient field; and

estimate a dip field based at least in part on the modified structure tensor.

19. The one or more computer-readable storage media of claim 18 wherein the instructions to determine a modified structure tensor comprises instructions to bias the gradient field.

20. The one or more computer-readable storage media of claim 18 wherein the instructions to determine a modified structure tensor comprises instructions to mask information associated with a subterranean object in the three-dimensional subterranean environment.

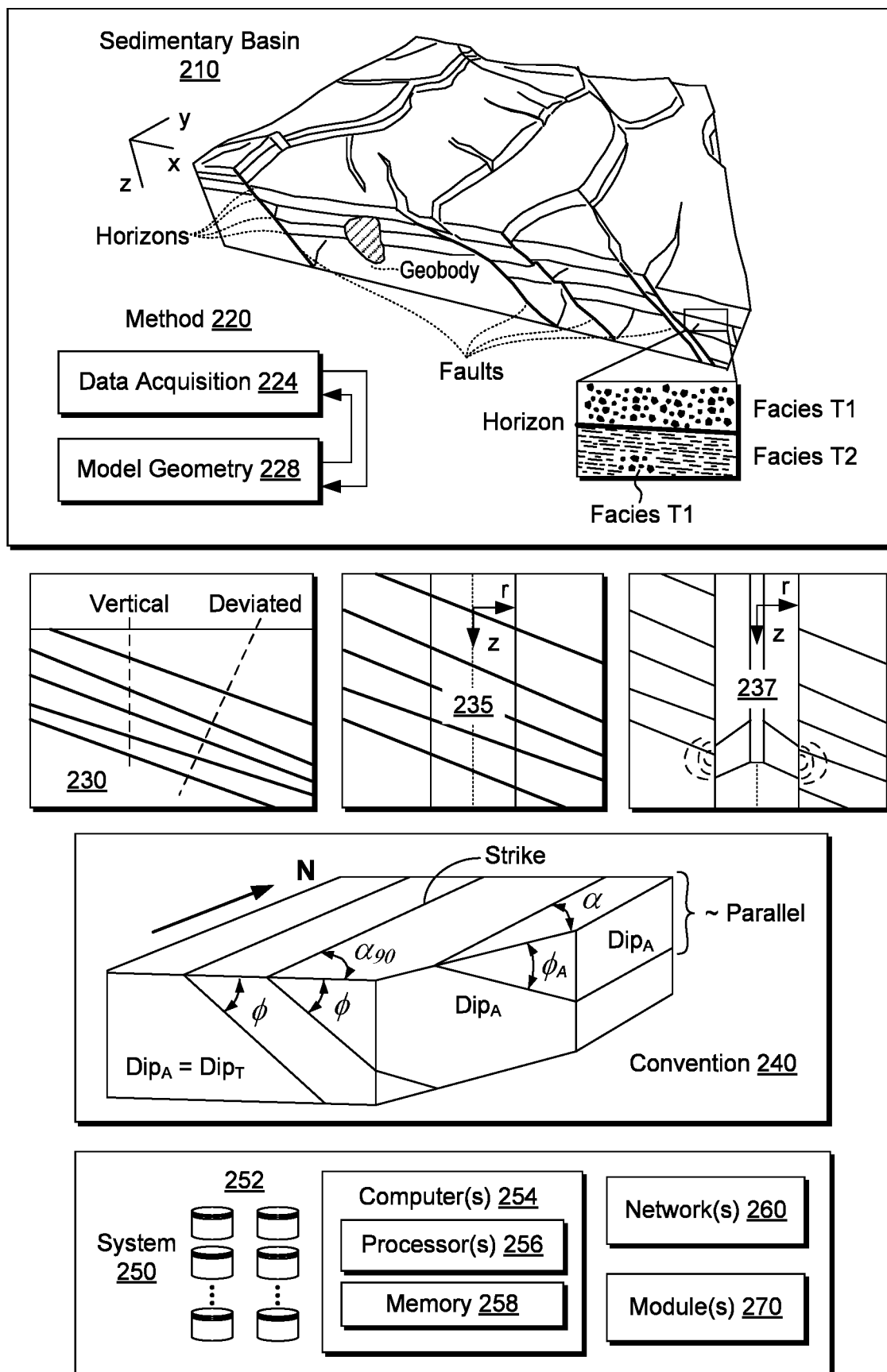


Fig. 2

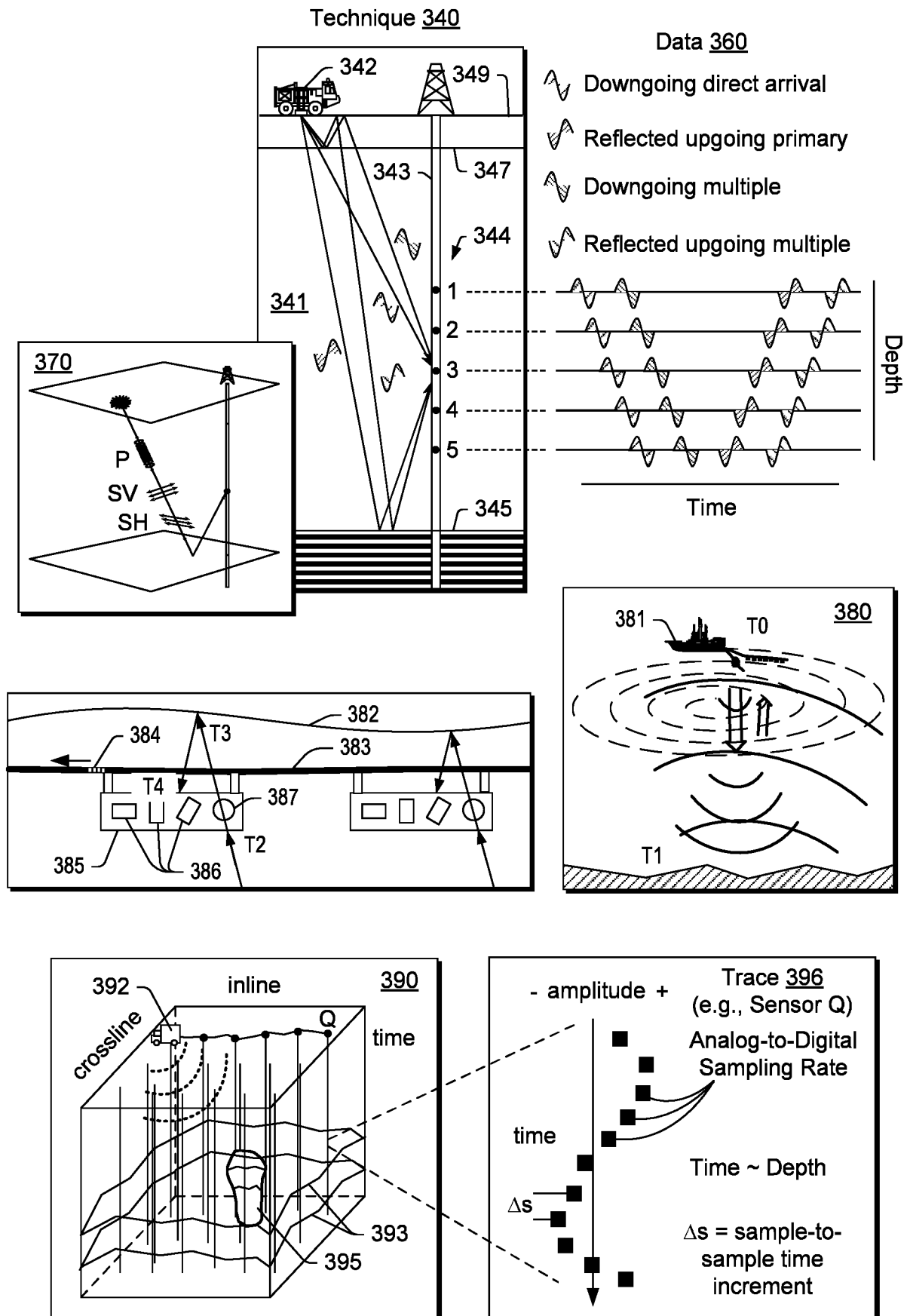


Fig. 3

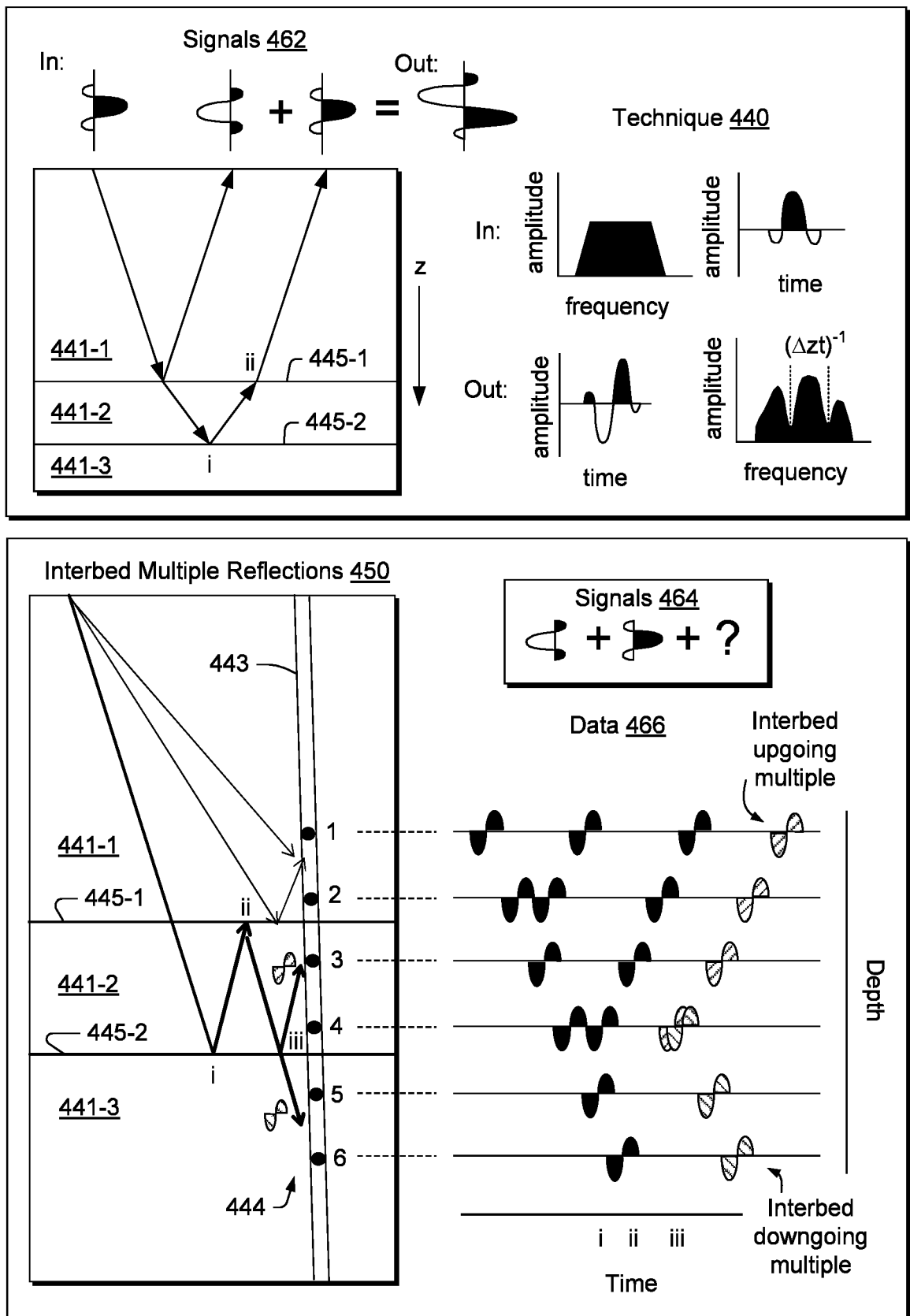


Fig. 4

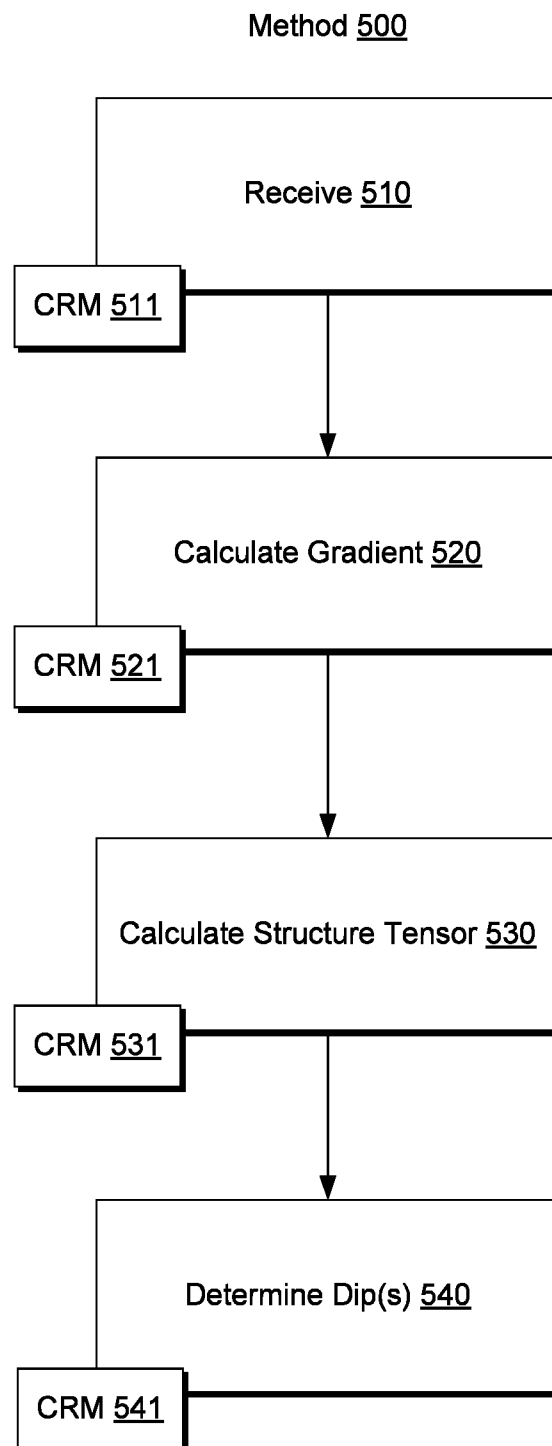


Fig. 5

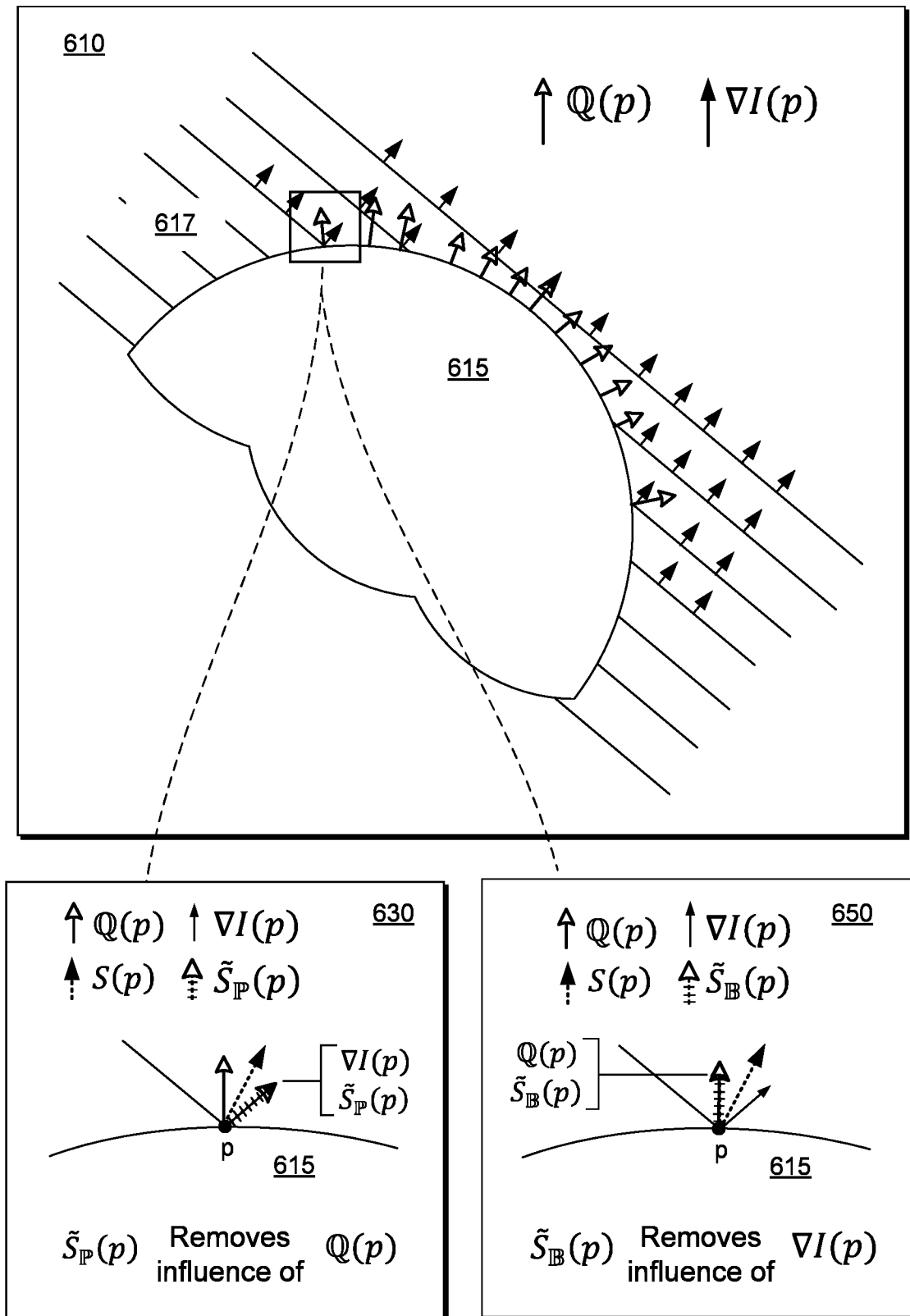


Fig. 6

Dip Estimation		Graphical User Interface (GUI) 700	
710	Input		
	Input Seismic	ZZZ-2-Stack-PETREL	X ?
	Input sample rate		
	Inline	25	Xline 25 Depth 6
	Extent from model (optional)		
720	Output		X ?
730	Output dip field name	ZZZ-2-Stack-PETREL-Dip-Field	
	Parameters		
	Output sample rate		
	Inline	100	Xline 100 Depth 48 ?
	Structure tensor window length		
	Inline	100	Xline 100 Depth 48 ?
	Minimum filter length		
	Inline	200	Xline 200 Depth 96 ?
	Maximum filter length		
740	Inline	600	Xline 600 Depth 288 ?
	Horizon guided parameters		
	Surface(s)		X ?
750	VOI		X ?
	Type	☒ MASK ? ☐ BIAS ?	
760	QC		
	QC Surface(s)		X ?
Apply OK Cancel			

Fig. 7

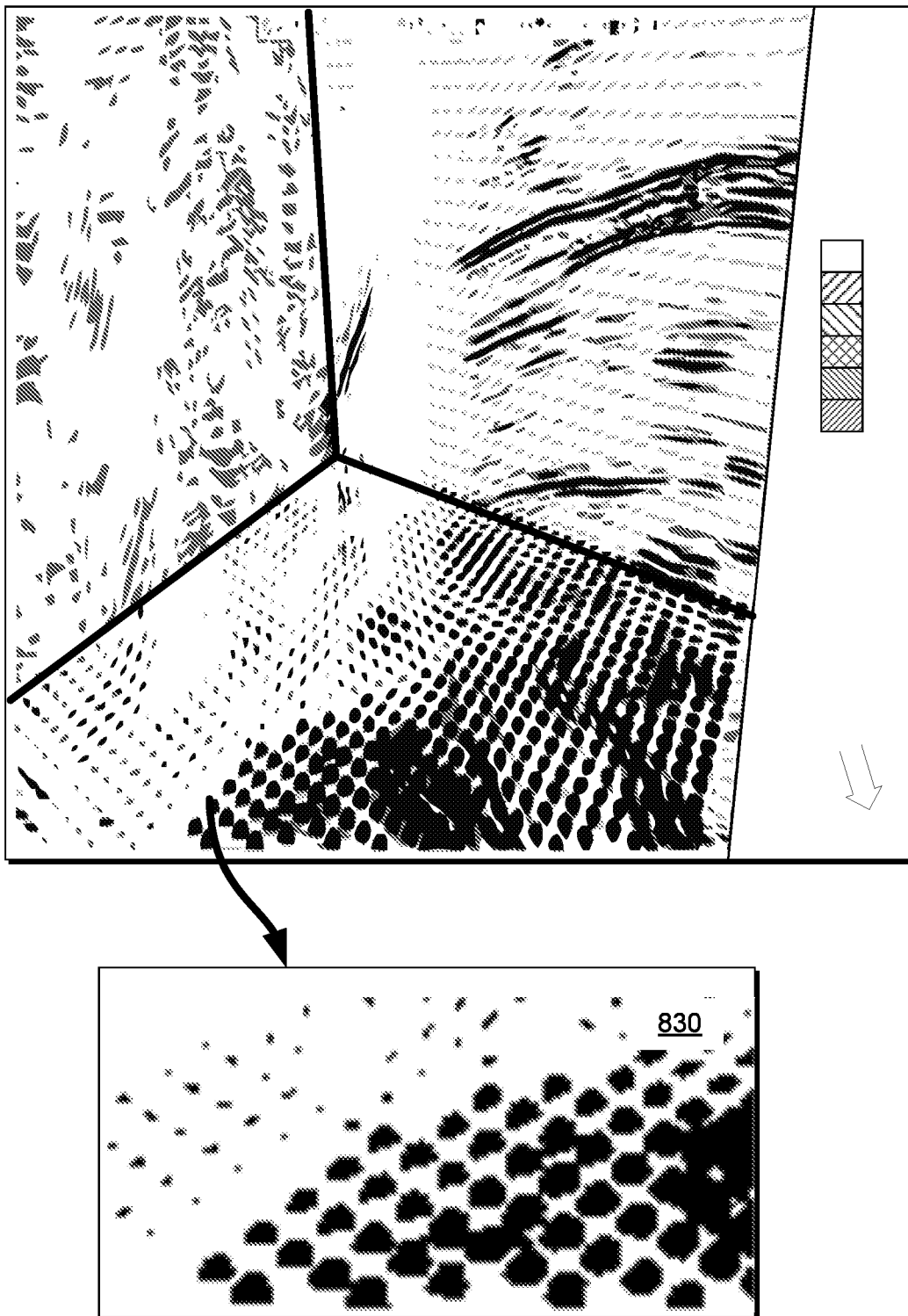
Graphical User Interface (GUI) 810

Fig. 8

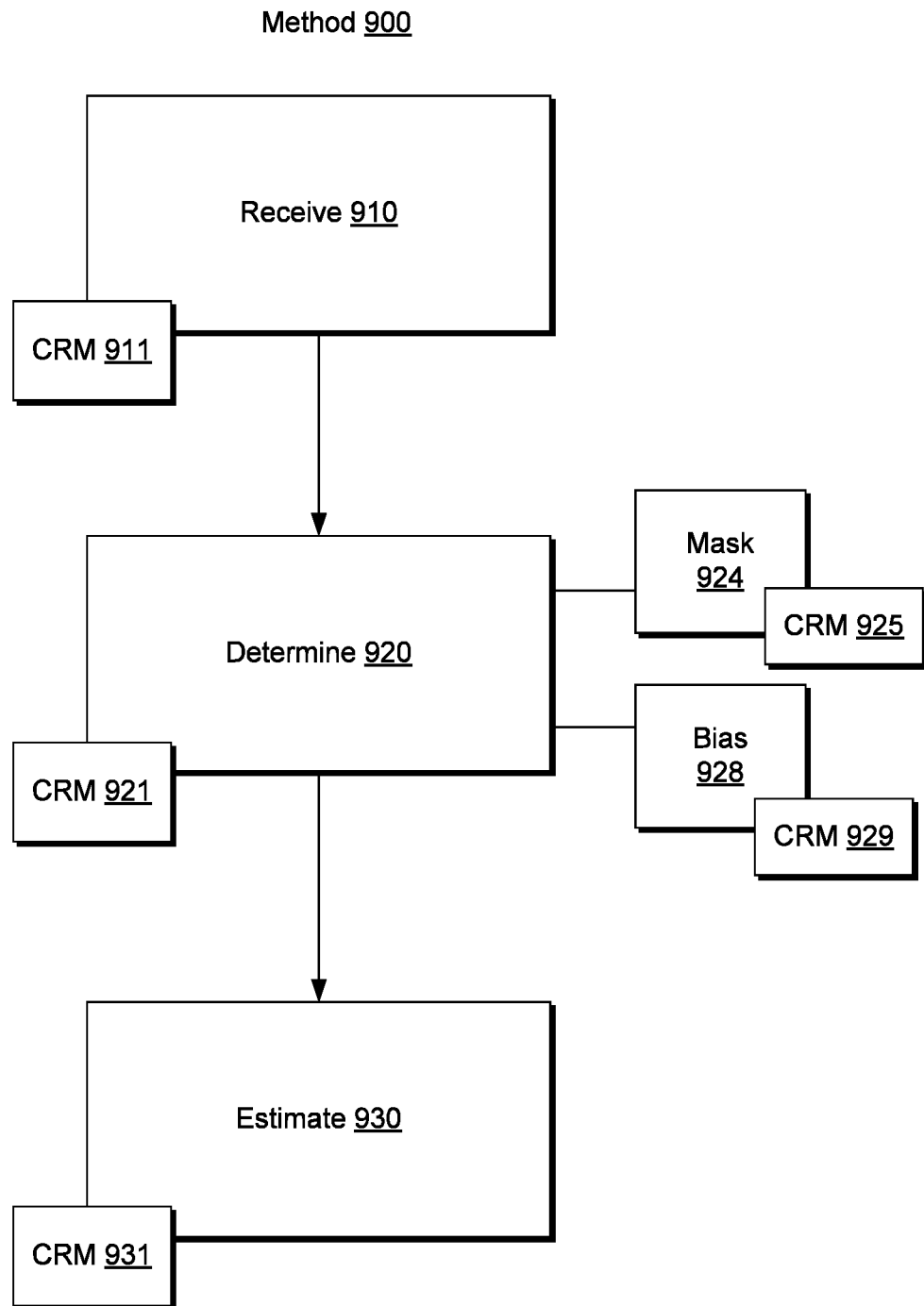


Fig. 9

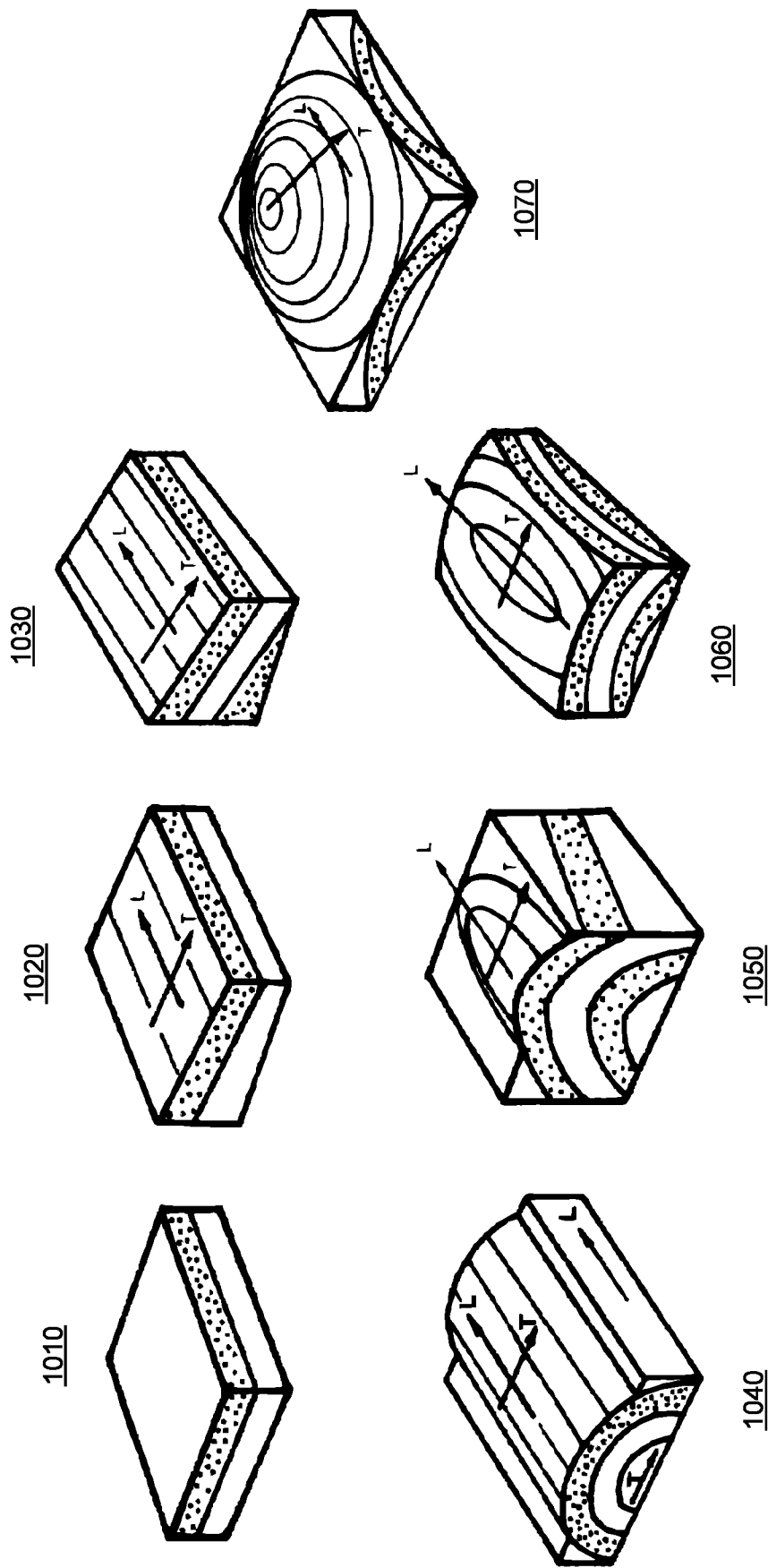
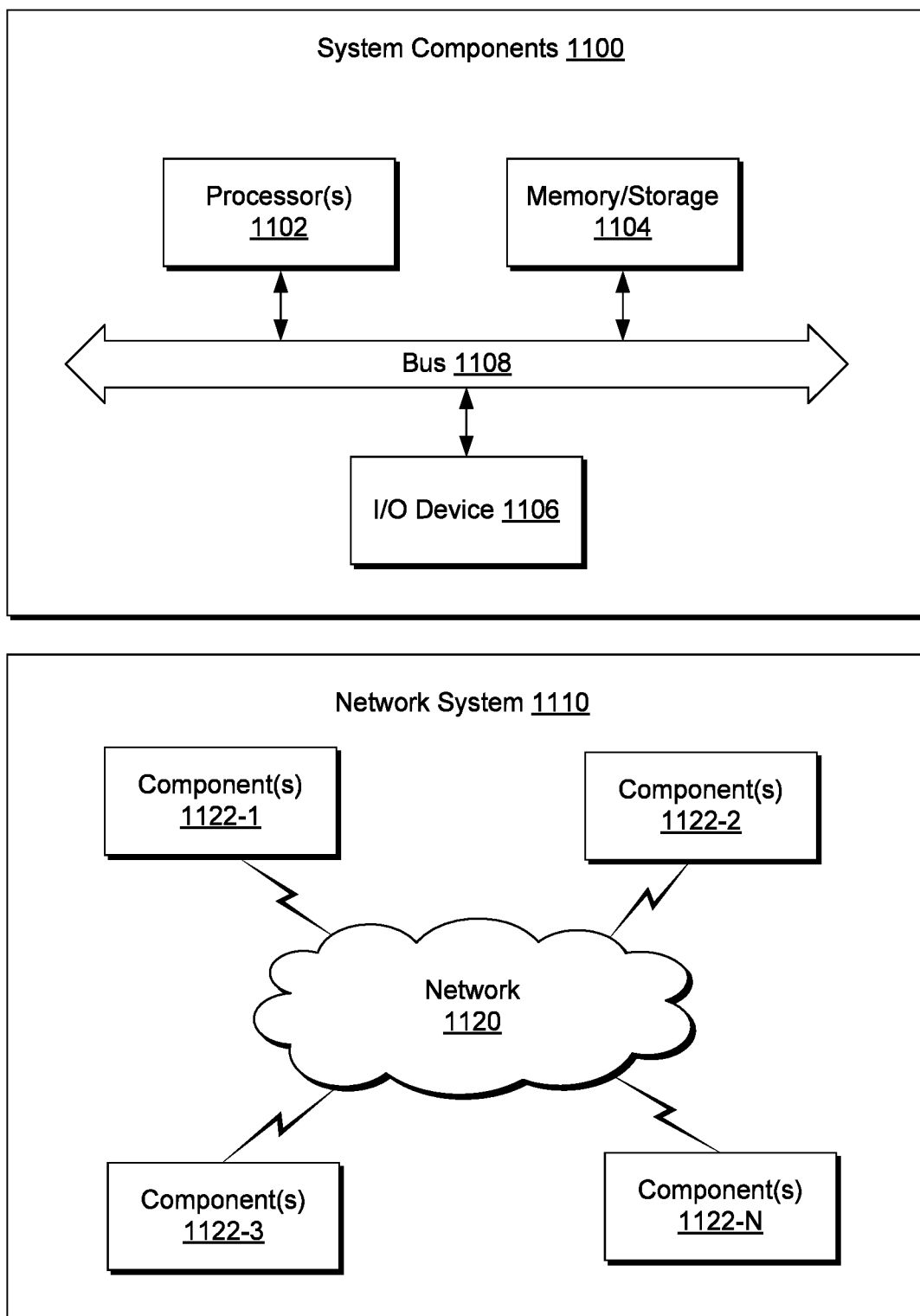


Fig. 10

**Fig. 11**

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2016/022329**A. CLASSIFICATION OF SUBJECT MATTER****G01V 1/48(2006.01)i**

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 1/48; G01V 1/30; G06T 17/00; G01V 1/28; G01V 1/34; G01V 1/36

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & Keywords: gradient field, seismic data, three-dimensional subterranean, structure tensor, dip field and sediment zone

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2015-0253445 A1 (WESTERNGECO L.L.C.) 10 September 2015 See paragraphs [0087]-[0101] and figures 9, 11.	1-2, 9-10, 15, 18
A		3-8, 11-14, 16-17, 19-20
A	US 2015-0301208 A1 (WESTERNGECO L.L.C.) 22 October 2015 See paragraphs [0021]-[0068] and figures 2-4.	1-20
A	US 2013-0064040 A1 (IMHOF, MATTHIAS G. et al.) 14 March 2013 See paragraphs [0082]-[0090] and figure 2.	1-20
A	US 2012-0320712 A1 (AQRAWI, AHMED ADNAN et al.) 20 December 2012 See paragraphs [0020]-[0104] and figures 1-14.	1-20
A	US 2014-0078140 A1 (LANDMARK GRAPHICS CORPORATION) 20 March 2014 See paragraphs [0024]-[0054] and figures 1-7.	1-20



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

12 December 2016 (12.12.2016)

Date of mailing of the international search report

12 December 2016 (12.12.2016)

Name and mailing address of the ISA/KR

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2016/022329

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US 2014-0078140 A1	20/03/2014	US 2011-205844 A1 US 2013-027398 A1 US 8274859 B2 US 8619499 B2 WO 2011-102922 A1	25/08/2011 31/01/2013 25/09/2012 31/12/2013 25/08/2011