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(54) Title: AUTO-VALIDATING EARTH INTERPRETATION AND MODELING SYSTEM

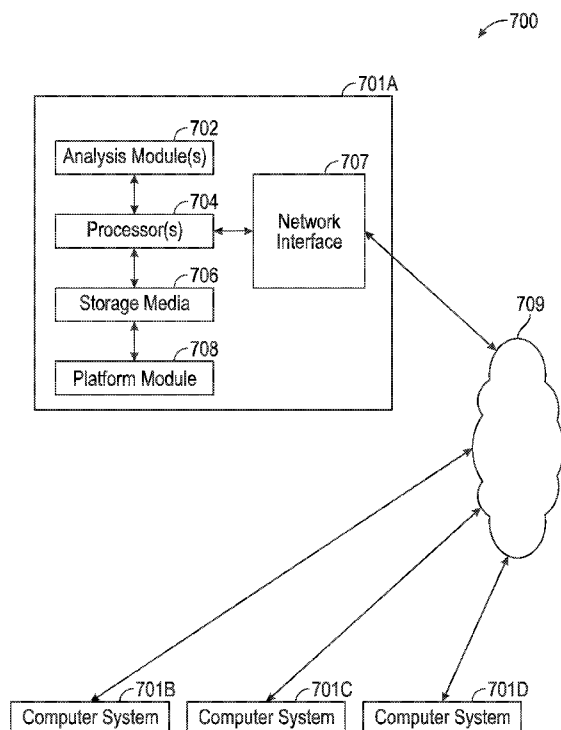


FIG. 7

(57) Abstract: Computing systems, methods, and computer-readable media for modeling a subsurface formation of interest are disclosed. More particularly, the techniques provide for simultaneous construction and operation of computer models including a geological computer model, a watertight volume structural computer model, a facies computer model, a simulation computer model, and a wellbore and pipeline computer model.



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AUTO-VALIDATING EARTH INTERPRETATION AND MODELING SYSTEM

Cross-Reference to Related Applications

[0001] This application claims priority to U.S. Provisional Patent Application having serial number 62/164,077, which was filed on May 20, 2015 and is incorporated herein by reference in its entirety.

Background

[0002] Oil and gas industry operations generally proceed in stages: exploration, appraisal, concept, design, and so on. This pathway from discovery to production of hydrocarbons involves several disciplines such as geophysics, petrophysics, geology, reservoir engineering, and production engineering, working in interpreting the measurements of the subsurface and modeling its behavior. The typical time span from discovery of a new oil or gas field to first production is in the range from five to ten years. Much of this is due to the sequential nature of the multi-disciplinary work involved.

[0003] Computer models of wells are employed to track and predict production. These models may be employed, for example, to determine the economical value for different well production scenarios. Furthermore, the parameters of several wells in a field may depend on one another, and thus computer models of the reservoir, including several wells, may be provided. The reservoir models may be employed to simulate and predict the effects of different production and/or other equipment parameters on the reservoir, and thus, for example, may be used to maximize the economical value of the reservoir or field.

Summary

[0004] According to examples of the present disclosure, a method of modeling a subsurface formation of interest is provided. The method comprises obtaining measurement data about the subsurface formation; performing, by at least one electronic processor, a first iteration of a geological computer model based, at least in part, on the measurement data, without human intervention; performing, by at least one electronic processor, a first iteration of a watertight volume structural computer model based, at least in part, on the first iteration of the geological computer model; performing, by at least one electronic processor, a first iteration of a facies

computer model based, at least in part, on the first iteration of the watertight volume structural computer model; performing, by at least one electronic processor, a first iteration of a simulation computer model based, at least in part, on the first iteration of the facies computer model; performing, by at least one electronic processor, a first iteration of a wellbore and pipeline computer model based, at least in part, on the first iteration of the simulation computer model; and generating an output representative of a first iteration result from the first iteration of the wellbore and pipeline computer model.

[0005] According to examples of the present disclosure, the method can further comprise obtaining, by the geological model, one or more refinements to the first iteration of the geological model; performing, by at least one electronic processor, a second iteration of a geological computer model based; at least in part, on the one or more refinements; performing, by at least one electronic processor, a second iteration of a watertight volume structural computer model based, at least in part, on the second iteration of the geological computer model; performing, by at least one electronic processor, a second iteration of a facies computer model based, at least in part, on the second iteration of the watertight volume structural computer model; performing, by at least one electronic processor, a second iteration of a simulation computer model based, at least in part, on the second iteration of the facies computer model; performing, by at least one electronic processor, a second iteration of a wellbore and pipeline computer model based, at least in part, on the second iteration of the simulation computer model; and generating an output representative of a second iteration result from the second iteration of the wellbore and pipeline computer model.

[0006] According to examples of the present disclosure, a computer system for modeling a subsurface formation of interest is provided. The system comprises at least one electronic processor and persistent memory storing computer-interpretable instructions configured to cause the at least one processor to perform a method. The method comprises obtaining measurement data about the subsurface formation; performing a first iteration of a geological computer model based, at least in part, on the measurement data, without human intervention; performing a first iteration of a watertight volume structural computer model based, at least in part, on the first iteration of the geological computer model; performing a first iteration of a facies computer model based, at least in part, on the first iteration of the watertight volume structural computer model; performing a first iteration of a simulation computer model based, at least in part, on the

first iteration of the facies computer model; performing a first iteration of a wellbore and pipeline computer model based, at least in part, on the first iteration of the simulation computer model; and generating an output representative of a first iteration result from the first iteration of the wellbore and pipeline computer model.

[0007] According to examples of the present disclosure, wherein performing the first iteration of the geological computer model further comprises constructing the watertight volume structural computer model prior to completion of the first iteration of the geological computer model.

[0008] According to examples of the present disclosure, wherein performing the first iteration of the watertight volume structural computer model further comprises constructing the facies computer model prior to completion of the first iteration of the watertight volume structural computer model.

[0009] According to examples of the present disclosure, wherein performing the first iteration of the facies computer model further comprises constructing the facies computer model prior to completion of the first iteration of the simulation computer model.

[0010] According to examples of the present disclosure, performing the first iteration of the simulation computer model further comprises constructing the wellbore and pipeline computer model prior to completion of the first iteration of the simulation computer model.

[0011] According to examples of the present disclosure, wherein the constructing the watertight volume structural computer model is performed in parallel with performing the first iteration of the geological computer model by at least one electronic graphics processing unit.

[0012] According to examples of the present disclosure, wherein the constructing the facies computer model is performed in parallel with performing the first iteration of the watertight volume structural computer model by at least one electronic graphics processing unit.

[0013] According to examples of the present disclosure, wherein the constructing the simulation computer model is performed in parallel with performing the first iteration of the facies computer model by at least one electronic graphics processing unit.

[0014] According to examples of the present disclosure, wherein the constructing the wellbore and pipeline computer model is performed in parallel with performing the first iteration of the simulation computer model by at least one electronic graphics processing unit.

Brief Description of the Drawings

[0015] The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate embodiments of the present teachings and together with the description, serve to explain the principles of the present teachings. In the figures:

[0016] FIG. 1 illustrates an example of a system that includes various management components to manage various aspects of a geologic environment, according to some embodiments.

[0017] FIG. 2 shows various aspects of an example of petroleum systems modeling including a sedimentary basin, model building, geological processes, and simulation processes, according to some embodiments.

[0018] FIG. 3 illustrates a method of modeling a subsurface environment, according to some embodiments.

[0019] FIG. 4 shows an example geological model of a subsurface environment including more than one well, according to some embodiments.

[0020] FIG. 5 shows one of the wells of FIG. 4.

[0021] FIG. 6 shows an example well and pipeline simulation model, according to some embodiments.

[0022] FIG. 7 illustrates an example computing system 700, in accordance with some embodiments.

Detailed Description

[0023] Reference will now be made in detail to embodiments, examples of which are illustrated in the accompanying drawings and figures. In the following detailed description, numerous specific details are set forth in order to provide a thorough understanding of the disclosure. However, it will be apparent to one of ordinary skill in the art that the disclosure may be practiced without these specific details. In other instances, well-known methods, procedures, components, circuits, and networks have not been described in detail so as not to unnecessarily obscure aspects of the embodiments.

[0024] It will also be understood that, although the terms first, second, etc. may be used herein to describe various elements, these elements should not be limited by these terms. These terms are used to distinguish one element from another. For example, a first object or step could be

termed a second object or step, and, similarly, a second object or step could be termed a first object or step, without departing from the scope of the present disclosure. The first object or step, and the second object or step, are both, objects or steps, respectively, but they are not to be considered the same object or step.

[0025] The terminology used in the description herein is for the purpose of describing particular embodiments and is not intended to be limiting. As used in this description and the appended claims, the singular forms “a,” “an” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will also be understood that the term “and/or” as used herein refers to and encompasses any possible combinations of one or more of the associated listed items. It will be further understood that the terms “includes,” “including,” “comprises” and/or “comprising,” when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof. Further, as used herein, the term “if” may be construed to mean “when” or “upon” or “in response to determining” or “in response to detecting,” depending on the context.

[0026] As discussed above, several disciplines, such as geophysics, petrophysics, geology, reservoir engineering, and production engineering, are typically employed to evaluate subsurface formations for oil and gas production. Oftentimes, work by one discipline expert is dependent on work by another discipline expert, which can lengthen the time to evaluate a particular subsurface formation. Some work practices and software tools that support the various discipline experts work in sequence. The petrophysicist analyzes the well log data and pass this information to the geologist. The geophysicist interprets the seismic data and passes this to the geologist. The geologist builds a geological model and passes this to the reservoir engineer. The reservoir engineer builds and runs a fluid flow simulation model and passes this to the facilities engineer, who designs and models the well and pipeline network.

[0027] Generally speaking, examples of the present disclosure relate to coupling the individual actions for performing subsurface modeling, which can reduce the overall time for interpretation and modeling and also can drive improved insight through much earlier and deeper collaboration between the involved disciplines. For example, examples of the present disclosure relate to aspects where as one of the discipline experts is working on his/her assigned task, a model for

the next stage is automatically built, run, and re-run as the expert progresses in the work. Even if simplifying assumptions would have to be made in constructing the model, this still gives the expert an assessment of the significance of the work currently being undertaken. Besides, the next expert in the chain will now be able to start interacting by refining the model as the inputs are gradually being refined.

[0028] Attention is now directed to processing procedures, methods, techniques, and workflows that are in accordance with some embodiments. Some operations in the processing procedures, methods, techniques, and workflows disclosed herein may be combined and/or the order of some operations may be changed.

[0029] In basin and petroleum systems modeling quantities such as temperature, pressure and porosity distributions within the sediments may be modeled by solving partial differential equations (PDEs) using a finite element method. 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.).

[0030] Various techniques for modeling of temperature, pressure, porosity, and geometry in basin and petroleum systems may be used in connection with the present disclosure. A commercially available modeling framework marketed as the PETROMOD.RTM. framework (Schlumberger Limited, Houston, Tex.) includes features for input of various types of information (e.g., seismic, well, geological, etc.) to model evolution of a sedimentary basin. Such a framework may provide for predicting if, and how, a reservoir has been charged with hydrocarbons, including source and timing of hydrocarbon generation, migration routes, quantities, hydrocarbon type, etc. Such a framework may include features for performing a backstripping technique as well as an associated forward modeling technique. As an example, a sedimentary basin may be modeled using a numerical technique that includes discretization of a spatial domain (e.g., 1D, 2D or 3D) via nodes and representing phenomena germane to that domain through sets of equations interconnected via segments or elements defined with respect to the nodes.

[0031] As an example, where the finite element method (FEM) is applied, a set of nodes may define a finite element grid. For example, steady-state and time simulation techniques may be employed. Further, where time is involved, numerical simulation may include another type of numerical technique such as a finite difference technique (e.g., discretization in time) in addition

to the FEM; for example, the FEM may be applied to a spatial domain and a finite difference technique may be applied to a time domain. In such an example, the FEM may solve for unknowns at discrete points in time, for example, while time marches forwards or backwards according to a finite difference approach. As another example, the FEM may be applied to a time domain (e.g., as well as a spatial domain). Further, as an example, a FEM technique may be applied in a so-called "inverse" manner where unknowns represent spatial positions for nodes of a finite element grid (e.g., consider specifying isotherms and solving for the locations of the isotherms, specifying a boundary and solving for the location of that boundary, etc.).

[0032] FIG. 1 illustrates 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.), according to some embodiments. 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).

[0033] 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.

[0034] 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.

[0035] 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.

[0036] 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 Figure 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.

[0037] 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.).

[0038] 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 enhancement 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.).

[0039] 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.).

[0040] 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.

[0041] 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.

[0042] 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.

[0043] 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).

[0044] 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.

[0045] 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, Figure 1 shows a satellite in communication with the network 155 that may be configured for communications,

noting that the satellite may additionally or instead include circuitry for imagery (e.g., spatial, spectral, temporal, radiometric, etc.).

[0046] 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.

[0047] 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 workflow 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.).

[0048] FIG. 2 shows various aspects of an example of petroleum systems modeling 200, including a sedimentary basin 210, model building 220, geological processes 230 and simulation processes 250. In general, petroleum systems modeling may be applied to various types of subsurface environments, including environments such as the underwater geologic environment 150 of FIG. 1.

[0049] In FIG. 2, the sedimentary basin 210 includes horizons, faults 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.). The model building 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 mentioned, a model may be subject to one or more cycles as part of an optimization procedure. 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).

[0050] To proceed to modeling of the geological processes 230, data are 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.).

[0051] The geological processes 230 may be part of a forward modeling process that performs calculations to simulate phenomena such as sediment burial, pressure and temperature changes, kerogen maturation and hydrocarbon expulsion, migration and accumulation. For example, a deposition block may account for sedimentation, erosion, salt doming, geologic event assignment; a pressure calculation block may account for pressure calculation and compaction; a heat flow analysis block may account for kinetics of thermal calibration parameters and calculate temperatures; a petroleum generation block may account for generation, adsorption and expulsion; a fluid analysis block may account for phase and compositions of fluid(s); a petroleum migration block may account for Darcy flow, diffusion, invasion percolation, and flowpath analysis; and a reservoir volumetrics block may account for column height of an accumulation, capillary entry pressure of a seal, leakage, break through, secondary cracking, and biodegradation.

[0052] With respect to simulation processes 250, one or more loops may be implemented, for example, according to time scales for various phenomena. In the example of FIG. 2, three loops are shown: Events, Basic and Migration. An events loop may characterize a geological period

in which one layer has been uniformly deposited or eroded or when a geological hiatus occurred. A total number of events (e.g., iterations of the loop) may be based on the order of the number of geological layers (e.g., approximately between 20 and 50). With respect to a basic loop, events may be subdivided into basic time steps, for example, with a solution for pressure or compaction and heat equations. The length of a basic time step can depend on deposition or erosion amounts and on a total duration of an event. For example, a total number of basic time steps may be between approximately 200 and 500. As to a migration loop, these may stem from further division of basic loop time steps. For example, migration steps may provide for a Darcy flow analysis where transported fluid amount for an element of a model may be restricted to a pore area or volume of that element (e.g., depending on dimensionality of the model element). A total number of steps for migration may be approximately 1,000 up to 50,000 or more, which may depend on flow activity, rock permeability, selected migration modeling technique, etc. In the example of FIG. 2, the loops are shown with some examples of scaling from X for the events loop, approximately 10X for the basic loop and approximately 100X or more for the migration loop.

[0053] As to transport processes (e.g., heat flow, pore pressure and compaction, Darcy flow migration processes and diffusion), a model may aim to account for a flow variable acting from a first location onto another location. For example, given temperature as a state variable and heat flow as a corresponding flow variable, a difference in temperature with respect to space (e.g., a temperature gradient) causes heat flow, which generally acts to decrease a temperature difference (e.g., drive toward an equilibrium temperature). As mentioned, boundary conditions may be provided to formulate a boundary value problem guided, for example, by an energy or mass balance to provide state and flow variable values with respect to time.

[0054] A formulated boundary value problem may be solved for state and flow variable values with respect to time using one or more numerical techniques. For example, the finite element method (FEM) may include defining finite elements that fill a geological space (e.g., in 1D, 2D or 3D) where time steps occur using a finite difference technique. In such an example, at individual time steps, a finite element model may be solved (e.g., in a linear or non-linear manner) and, once solved, a finite difference technique may act to "perturb" or "estimate" state values for a forward time (e.g., which may be in the future or past) or reverse time (backward time, e.g., which may be in the future or past), where these values are used as an initial estimate

to solve the finite element model at the iterated time (e.g., finite element method for spatial modeling and finite difference for temporal modeling).

[0055] In an example embodiment, neighboring finite elements may be linked at a shared boundary (e.g., a point, a line or a surface) where the boundary conditions for two or more neighboring finite elements may be matched (e.g., energy-wise, material-wise, etc.). As an example, consider a mass of fluid exiting one finite element and entering a neighboring finite element (e.g., adjacent finite element). Where the porosity of the two finite elements differs, fluid velocity may differ for individual finite elements while mass and momentum are conserved across their shared boundary. Similar types of examples exist for other phenomena such as temperature and heat energy.

[0056] With respect to solving a finite element model using the finite element method (FEM), inversion of a matrix can provide for a solution vector (e.g., for state variables of various finite elements). As an example, a finite element model may include many finite elements (e.g., approximately thousands) with many unknowns (e.g., approximately thousands). Larger finite element models can include, for example, more than approximately a million finite elements with over approximately a million unknowns. Solution time or resources requirements may depend on the number of unknowns, number of linked equations, linearity or nonlinearity of a formulation of equations, property dependence on one or more state variables, etc. Solution time or resource requirements may be determined on the basis of a relationship between matrix inversion and number of unknowns as well as knowledge of other factors such as matrix diagonality. In general, solution time or resource requirements may scale nonlinearly (e.g., exponentially) with respect to number of finite elements (e.g., number of unknowns). As an example, doubling the number of finite elements along one dimension can increase computing effort by an order of magnitude. Accordingly, some trade-offs may exist as to solution accuracy (e.g., more finite elements) and solution timing (e.g., for fixed computing resources) or solution requirements (e.g., ability to increase number of cores, memory, etc.).

[0057] FIG. 3 illustrates a method of modeling a subsurface formation 300, according to examples of the present disclosure. At 305, raw measurement data of the environment of interest to be modeled are obtained. The raw measurement data can include, but are not limited to, seismic data and well log data that can be acquired during any phase of well's history (drilling, completion, producing, or abandoning) and can be acquired while boreholes are drilled for the oil

and gas, groundwater, mineral and geothermal exploration, as well as part of environmental and geotechnical studies. The well log data can include, but are not limited to, data acquired by resistivity logging, borehole imaging, porosity logs, density scans, neutron porosity measurements, sonic logging measurements, etc., as are known in the art.

[0058] At 310, a user, such as a geophysicist, initiates the construction and processing of one or more iterations of a first computer model (geological model) of the environment of interest by at least one processor of a computer system. The geological model can be any type of geological model and generally is used to create a computerized representation of portions of the Earth's crust based on geophysical and geological observations made on or below the Earth's surface. Example geological models can include those described in "Volume Based Modeling – Automated Construction of Complex Structural Models," by L. Souche, F. Lepage, and G. Iskenova, 75th EAGE Conference & Exhibition incorporating SPE EUROPEC 2013, London, UK, 10-13 June 2013. FIG. 4 shows an example of a geological model. Geological modeling (or geomodeling) generally involves preliminary analysis of geological context of the domain of study; interpretation of available data and observations as point sets or polygonal lines (e.g. "fault sticks" corresponding to faults on a vertical seismic section); construction of a structural model describing the main rock boundaries (horizons, unconformities, intrusions, faults); definition of a three-dimensional mesh honoring the structural model to support volumetric representation of heterogeneity solving a series of partial differential equations that govern physical processes in the subsurface (e.g. seismic wave propagation, fluid transport in porous media).

[0059] If the geological model has already been preconfigured or if several geological models have been constructed, the user can select an appropriate geological from among those that is suitable for the environment of interest. The computer system can create the geological model using the raw measurement data, such as seismic data and well log data discussed above at 305, and define surfaces, such as paleo-horizons and faults, by interpreting the raw measurement data. The computer system can perform one or more iterations of the model without input from the user. The one or more iterations of the geological model will be less constrained by realities than a more refined model adjusted by the user. As the model runs, the user can further refine the model using knowledge of the environment of interest. For example, the user may know that in a certain area, geological tectonic history may exclude certain types of faults, such as faults in a

thrust belt where continental plates collide are fundamentally different from faults in an extensional area where continental plates drift apart. The user may thus modify the initial model built by the computer system to take these issues into account. The user can interpret the seismic faults and horizons and the geological model can build pseudo-zones and grids, which can be overlaid as a color code on the seismic data. This can give the interpreter an idea of the significance of the minute details they spend days on today versus how complete was their analysis of the fault and horizon network. As the user continues to refine the geological mode, the real zones will be better represented and the uncertainties will be better known, which can result in reducing the sensitivities used in the geological model.

[0060] At 315, the user and/or another user, initiates the construction and processing of one or more iterations of second computer model (e.g., watertight structural model) that isolates, e.g., the volume on one side of a fault from the volume on the other side. Examples of the watertight structure model can include those described in “Volume Based Modeling – Automated Construction of Complex Structural Models,” by L. Souche, F. Lepage, and G. Iskenova, 75th EAGE Conference & Exhibition incorporating SPE EUROPEC 2013, London, UK, 10-13 June 2013. In some examples, the watertight volume structural computer model can be constructed prior to completion of the first iteration of the geological computer model. For example, a volume-based modeling method may include receiving input data, such as the output from 310; generating a volume mesh, which may be, for example, an unstructured tetrahedral mesh; calculating implicit function values, which may represent stratigraphy; extracting one or more horizon surfaces as iso-surfaces of the implicit function; and generating a watertight model of geological layers, which may optionally be obtained by subdividing a model at least in part via implicit function values. As an example, an implicit function calculated for a geologic environment includes isovalues that may represent stratigraphy of modeled layers. For example, depositional interfaces identified via interpretations of seismic data (e.g., signals, reflectors, etc.) and/or on borehole data (e.g., well tops, etc.) may correspond to iso-surfaces of the implicit function. As an example, where reflectors correspond to isochronous geological sequence boundaries, an implicit function may be a monotonous function of stratigraphic age of geologic formations.

[0061] At 320, the user and/or another user, such as a geologist, or an event triggered by data from one or more data collection modules associated with the area of interest, *i.e.*, sub-surface

formation, initiates the construction and processing of one or more iterations of a third model (a facies and petrophysical model) that populates the volumes from the volume-based model at 315 with properties, such as, porosity, permeability, facies, etc., from nearby public data and/or multi-client regional geological models. Facies models are known in the art. Examples of facies and petrophysical models can include those described in the PETREL[®] framework discussed above. In some examples, the facies and petrophysical computer model can be constructed prior to completion of the first iteration of the watertight volume structural computer model. A coarse reservoir simulation is run continuously as the geologist builds the model, giving an objective function of the reservoir. The reservoir simulation models fluid flow during petroleum drainage to predict production and provide information for its optimization, where the distance scale is meter to kilometers and the time scale is months to years. In some cases, the flow is dynamic, the model geometry is static, remaining unchanged during simulation. In other cases, several reservoirs in the world have geometries that change during production, *e.g.*, Ekofisk in the North Sea. In these cases, the geometrical deformation can be simulated resulting from production of hydrocarbon and injection of water in the reservoir. Such geomechanical simulation may be built into the flow of FIG. 3 and run continuously when the geology necessitates so. The objective function can be related to economic profitability of a development, such as recovery rate of the resource. Parameters, including but are not limited to, reservoir properties (*i.e.*, permeability) and human-induced elements (*i.e.*, the number of wells that are to be drilled or have been drilled to produce the reservoir, where water is injected to push oil out, when such injection of water begins and at what pressures, water injection rate, steam injection rate, artificial lift methods, and efficiency, etc.), may be perturbed by the system and run in an uncertainty estimation process, giving sensitivities of the recovery rates. Continuing with the example of FIG. 4, FIG. 5 shows one of the wells of FIG. 4 in detail with a well log data 505 (the ribbon alongside the well). The well log data contains measurements that can be used to derive the porosity, permeability, and other reservoir or source rock properties along the trajectory of the well. If the structure of the subsurface is known, the topology, as shown by the horizons in FIG. 4, geostatistical methods may be used to estimate how these reservoir properties vary spatially away from the wells. Any well data, including publically-accessible data on wells and data from or for wells owned by the client, could be used for the geostatistical methods and properties from these wells could be used to the automated model building.

[0062] The parameters discussed above that can be perturbed can be considered in isolation to determine its impact on the modeling outcome. For example, consider the parameter related to the placement of a water injection well at a certain location. The system would run a simulation of the oil production with the injection well and without it. If the well has a big impact on the total recoverable oil or the production rate or other parameters that will impact the economics of the development, then that would say there's a large sensitivity to that parameter.

[0063] At 325, the user and/or another user, such as a reservoir engineer, initiates the construction and processing of one or more iterations of a forth model (simulation model), having the above-discussed parameters augmented with typical ranges where the user has not given explicit control on the ranges and the uncertainty estimation process is run continuously, giving indications on the sensitivities. A simulation model is a computational grid that can be used for simulating the flow of fluids and gases in the subsurface. Simulation models are known in the art. Examples of simulation models can include those described in the PETREL[®] framework discussed above. In some examples, the simulation computer model can be constructed prior to completion of the first iteration of the facies and petrophysical computer model. For example, a typical range for permeability can be from about 1 nanodarcy to about 1 millidarcy. A typical range for a water injection rate can be from about a thousand barrels per day to about hundred thousand barrels per day. Consider the example where the computer is running the simulations as above, varying permeability from 1 nanodarcy to 1 millidarcy (that is, testing the impact of the permeability with a large number of reservoir simulation runs with different values of permeability in that range) and varying the injection rate of an injection well from 1,000 barrels per day to 100,000. As a result of the simulations, it may be discovered that the permeability will have much greater impact on the objective function (ultimate production, economics, or whatever the goal for the optimization is) than water injection rate. This means that there is a greater sensitivity to the permeability. The indications of the sensitivities can be represented by one or more different modalities. For example, the indications can be visually displayed as a “traffic light” arrangement, where some parameters can be indicated as having more impact on the objective function, such as it may be better to determine the actual permeability than the actual water injection rate. Hence, the user should spend more time making sure actions are taken towards deriving an accurate model for permeability than water injection rates.

[0064] At 330, as the user and/or another user, such as a reservoir engineer, designs one or more development wells, a fifth model (wellbore and pipeline simulation model) is automatically created and constantly run in an uncertainty loop with a set of typical pipeline configurations to give an idea what investment range may be required to produce the reservoir and take full advantage of the wells being planned. A wellbore and pipeline simulation model simulates the flow of hydrocarbons, water, etc., through the wells and the pipeline network. Wellbore and pipeline simulation models are known in the art. FIG. 6 shows an example of a wellbore and pipeline simulation model. The “uncertainty loop” is what's described above, but for clarity, following permeability – water injection example: Multiple simulations are run, for example one for each of these value pairs (columns in the table, the parameters would be created by some mathematical optimization technique, values just given here as an illustration):

Permeability [in nanodarcy]	10	150	900	2.4	630	750	2.4	140	160
Injection rate [in 1000 barrels per day]	90	3	91	24	26	2	50	37	97

[0065] Testing pairs of parameters, one column at a time, running a reservoir simulation for one, some, or each pair, may be referred to as the “uncertainty loop”.

[0066] It is not only the reservoir model that may have different parameters; the network of pipelines that connect the wells does have a range of possibilities also. This could be how you connect them (pattern of pipelines, see one example in FIG. 6), what kind of equipment you have at the hubs connecting different pipelines, pump equipment you have along the way, any equipment you may install to prevent flow issues, etc.

[0067] Similar to the example of permeability and injection rate, the impact of these parameters can also be examined by running different scenarios and seeing how it will impact flow – and what it will cost to develop. For example, there is limited use in developing a reservoir to produce 200,000 barrels per day if the pipeline network can only take 100,000. Since there are costs with everything, upgrading the pipeline network to a 200,000 barrel per day capacity may not make sense.

[0068] The wellbore and pipeline simulation can simulate a regional petroleum system model that can be shared by several oil companies. This model can be automatically augmented with additional field data within the realm of any of these companies. The petroleum system model

simulation is constantly rerun with this additional model data to provide likely petroleum composition and/or reservoir properties. This allows multi-client (service company, above) regional models to be enriched inside the individual companies, without building the overall model from scratch and without a sequential process.

[0069] The service company exploration geologist would not have access to the oil company proprietary data (for example the well in FIG. 5). When an oil company geologist picks up the model from the service company, that well could be added. This could lead to an update of the understanding of the structure of the reservoir or the properties (porosity, permeability, etc.). This is just as in the example earlier, except that it's now the oil company geologist updating a model by a service company geologist.

[0070] The input to the additional model data in this example would be the well in FIG. 5. Constantly rerun means any time any additional data is provided or any aspect of the model is updated, the system would automatically trigger a rerun of the petroleum system simulation process, giving presumably gradually improving predictions of the true geology. Economic simulations can be run on the above, continuously, creating a true living model from seismic to economics, from exploration through production.

[0071] The above method can be implemented in a cloud IT infrastructure, where compute resources are flexibly available and can be leveraged entirely in the background while the expert is working.

[0072] Geologic interpretations, models and/or other interpretation aids may be refined in an iterative fashion; this concept is applicable to embodiments of the present methods discussed herein. This can include use of feedback loops executed on an algorithmic basis, such as at a computing device (e.g., computing system 700, FIG. 7), and/or through manual control by a user who may make determinations regarding whether a given step, action, template, model, or set of curves has become sufficiently accurate for the evaluation of the subsurface three-dimensional geologic formation under consideration.

[0073] At 335, the method outputs the solution. The outputting may take on various forms. The outputting may include displaying a pictorial representation of at least a part of the reservoir, displaying one or more graphs depicting one or more physical parameters, delivering data to a separate process (e.g., to determine whether to extract petroleum), or other outputting techniques.

[0074] In some examples, the methods of the present disclosure may be executed by a computing system. FIG. 7 illustrates an example of such a computing system 700, in accordance with some embodiments. The computing system 700 may include a computer or computer system 701A, which may be an individual computer system 701A or an arrangement of distributed computer systems. The computer system 701A includes one or more analysis modules 702 that are configured to perform various tasks according to some embodiments, such as one or more methods disclosed herein. To perform these various tasks, the analysis module 702 executes independently, or in coordination with, one or more processors 704, which is (or are) connected to one or more storage media 706. The processor(s) 704 is (or are) also connected to a network interface 707 to allow the computer system 601A to communicate over a data network 709 with one or more additional computer systems and/or computing systems, such as 701B, 701C, and/or 701D (note that computer systems 701B, 701C and/or 701D may or may not share the same architecture as computer system 701A, and may be located in different physical locations, e.g., computer systems 701A and 701B may be located in a processing facility, while in communication with one or more computer systems such as 701C and/or 701D that are located in one or more data centers, and/or located in varying countries on different continents).

[0075] A processor may include hardware or electronic processors, such as a microprocessor, microcontroller, graphic processing unit (GPU), processor module or subsystem, programmable integrated circuit, programmable gate array, or another control or computing device.

[0076] The processor system 700 may include one or more processors 702 of varying core configurations (including multiple cores) and clock frequencies. The one or more processors 702 may be operable to execute instructions, apply logic, etc. It will be appreciated that these functions may be provided by multiple processors or multiple cores on a single chip operating in parallel and/or communicably linked together. In at least one embodiment, the one or more processors 702 may be or include one or more GPUs.

[0077] The storage media 706 may be implemented as one or more computer-readable or machine-readable storage media. Note that while in the example embodiment of FIG. 7 storage media 706 is depicted as within computer system 701A, in some embodiments, storage media 706 may be distributed within and/or across multiple internal and/or external enclosures of computing system 701A and/or additional computing systems. Storage media 706 may include

one or more different forms of memory including semiconductor memory devices such as dynamic or static random access memories (DRAMs or SRAMs), erasable and programmable read-only memories (EPROMs), electrically erasable and programmable read-only memories (EEPROMs) and flash memories, magnetic disks such as fixed, floppy and removable disks, other magnetic media including tape, optical media such as compact disks (CDs) or digital video disks (DVDs), BLURAY® disks, or other types of optical storage, or other types of storage devices. Note that the instructions discussed above may be provided on one computer-readable or machine-readable storage medium, or may be provided on multiple computer-readable or machine-readable storage media distributed in a large system having possibly plural nodes. Such computer-readable or machine-readable storage medium or media is (are) considered to be part of an article (or article of manufacture). An article or article of manufacture may refer to any manufactured single component or multiple components. The storage medium or media may be located either in the machine running the machine-readable instructions, or located at a remote site from which machine-readable instructions may be downloaded over a network for execution.

[0078] In some embodiments, computing system 700 contains one or more platform module(s) 708. In the example of computing system 700, computer system 701A includes the platform module 708. In some embodiments, a single platform module may be used to perform some aspects of one or more embodiments of the methods disclosed herein. In other embodiments, a plurality of platform modules may be used to perform some aspects of methods herein.

[0079] It should be appreciated that computing system 700 is merely one example of a computing system, and that computing system 700 may have more or fewer components than shown, may combine additional components not depicted in the example embodiment of FIG. 7, and/or computing system 700 may have a different configuration or arrangement of the components depicted in FIG. 7. The various components shown in FIG. 7 may be implemented in hardware, software, or a combination of both hardware and software, including one or more signal processing and/or application specific integrated circuits.

[0080] Further, the steps in the processing methods described herein may be implemented by running one or more functional modules in information processing apparatus such as general purpose processors or application specific chips, such as ASICs, FPGAs, PLDs, or other appropriate devices. These modules, combinations of these modules, and/or their combination with general hardware are included within the scope of the present disclosure.

[0081] 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 method may be implemented in a distributed environment (e.g., wholly or in part as a cloud-based service).

[0082] Geologic interpretations, models, and/or other interpretation aids may be refined in an iterative fashion; this concept is applicable to the methods discussed herein. This may include use of feedback loops executed on an algorithmic basis, such as at a computing device (e.g., computing system 700, FIG. 7), and/or through manual control by a user who may make determinations regarding whether a given step, action, template, model, or set of curves has become sufficiently accurate for the evaluation of the subsurface three-dimensional geologic formation under consideration.

[0083] Note that the processes discussed above may be parallelized in computer hardware in order to improve performance. That is, implementations of the disclosure are particularly suited to execution on parallel processing hardware. To that end, Graphical Processing Units (GPUs) may be used to handle the above-discussed processing least partially in parallel.

[0084] Although the preceding description has been described herein with reference to particular means, materials, and embodiments, it is not intended to be limited to the particular disclosed herein. By way of further example, embodiments may be utilized in conjunction with a handheld system (i.e., a phone, wrist or forearm mounted computer, tablet, or other handheld device), portable system (i.e., a laptop or portable computing system), a fixed computing system (i.e., a desktop, server, cluster, or high performance computing system), or across a network (i.e., a cloud-based system). As such, embodiments extend to all functionally equivalent structures, methods, uses, program products, and compositions as are within the scope of the appended claims.

WHAT IS CLAIMED IS:

1. A method of modeling a subsurface formation of interest, the method comprising:
 - obtaining measurement data about the subsurface formation;
 - performing, by at least one electronic processor, a first iteration of a geological computer model based, at least in part, on the measurement data, without human intervention;
 - performing, by at least one electronic processor, a first iteration of a watertight volume structural computer model based, at least in part, on the first iteration of the geological computer model;
 - performing, by at least one electronic processor, a first iteration of a facies computer model based, at least in part, on the first iteration of the watertight volume structural computer model;
 - performing, by at least one electronic processor, a first iteration of a simulation computer model based, at least in part, on the first iteration of the facies computer model;
 - performing, by at least one electronic processor, a first iteration of a wellbore and pipeline computer model based, at least in part, on the first iteration of the simulation computer model; and
 - generating an output representative of a first iteration result from the first iteration of the wellbore and pipeline computer model.
2. The method of claim 1, further comprising:
 - obtaining, by the geological model, one or more refinements to the first iteration of the geological model;
 - performing, by at least one electronic processor, a second iteration of a geological computer model based; at least in part, on the one or more refinements;
 - performing, by at least one electronic processor, a second iteration of a watertight volume structural computer model based, at least in part, on the second iteration of the geological computer model;
 - performing, by at least one electronic processor, a second iteration of a facies computer model based, at least in part, on the second iteration of the watertight volume structural computer model;

performing, by at least one electronic processor, a second iteration of a simulation computer model based, at least in part, on the second iteration of the facies computer model;

performing, by at least one electronic processor, a second iteration of a wellbore and pipeline computer model based, at least in part, on the second iteration of the simulation computer model; and

generating an output representative of a second iteration result from the second iteration of the wellbore and pipeline computer model.

3. The method of claim 1, wherein performing the first iteration of the geological computer model further comprises constructing the watertight volume structural computer model prior to completion of the first iteration of the geological computer model.

4. The method of claim 3, wherein the constructing the watertight volume structural computer model is performed in parallel with performing the first iteration of the geological computer model by at least one electronic graphics processing unit.

5. The method of claim 1, wherein performing the first iteration of the watertight volume structural computer model further comprises constructing the facies computer model prior to completion of the first iteration of the watertight volume structural computer model.

6. The method of claim 5, wherein the constructing the facies computer model is performed in parallel with performing the first iteration of the watertight volume structural computer model by at least one electronic graphics processing unit.

7. The method of claim 1, wherein performing the first iteration of the facies computer model further comprises constructing the facies computer model prior to completion of the first iteration of the simulation computer model.

8. The method of claim 7, wherein the constructing the simulation computer model is performed in parallel with performing the first iteration of the facies computer model by at least one electronic graphics processing unit.

9. The method of claim 1, wherein performing the first iteration of the simulation computer model further comprises constructing the wellbore and pipeline computer model prior to completion of the first iteration of the simulation computer model.

10. The method of claim 9, wherein the constructing the wellbore and pipeline computer model is performed in parallel with performing the first iteration of the simulation computer model by at least one electronic graphics processing unit.

11. A computer system for modeling a subsurface formation of interest, the system comprising at least one electronic processor and persistent memory storing computer-interpretable instructions configured to cause the at least one processor to perform a method comprising:

- obtaining measurement data about the subsurface formation;
- performing a first iteration of a geological computer model based, at least in part, on the measurement data, without human intervention;
- performing a first iteration of a watertight volume structural computer model based, at least in part, on the first iteration of the geological computer model;
- performing a first iteration of a facies computer model based, at least in part, on the first iteration of the watertight volume structural computer model;
- performing a first iteration of a simulation computer model based, at least in part, on the first iteration of the facies computer model;
- performing a first iteration of a wellbore and pipeline computer model based, at least in part, on the first iteration of the simulation computer model; and
- generating an output representative of a first iteration result from the first iteration of the wellbore and pipeline computer model.

12. The computer system of claim 11, wherein the instructions are further configured to cause the at least one processor to perform:

- obtaining one or more refinements to the first iteration of the geological model;

performing a second iteration of a geological computer model based; at least in part, on the one or more refinements;

performing a second iteration of a watertight volume structural computer model based, at least in part, on the second iteration of the geological computer model;

performing a second iteration of a facies computer model based, at least in part, on the second iteration of the watertight volume structural computer model;

performing a second iteration of a simulation computer model based, at least in part, on the second iteration of the facies computer model;

performing a second iteration of a wellbore and pipeline computer model based, at least in part, on the second iteration of the simulation computer model; and

generating an output representative of a second iteration result from the second iteration of the wellbore and pipeline computer model.

13. The computer system of claim 11, wherein performing the first iteration of the geological computer model further comprises constructing the watertight volume structural computer model prior to completion of the first iteration of the geological computer model.

14. The computer system of claim 13, wherein the constructing the watertight volume structural computer model is performed in parallel with performing the first iteration of the geological computer model by at least one electronic graphics processing unit.

15. The computer system of claim 11, wherein performing the first iteration of the watertight volume structural computer model further comprises constructing the facies computer model prior to completion of the first iteration of the watertight volume structural computer model.

16. The computer system of claim 15, wherein the constructing the facies computer model is performed in parallel with performing the first iteration of the watertight volume structural computer model by at least one electronic graphics processing unit.

17. The computer system of claim 11, wherein performing the first iteration of the facies computer model further comprises constructing the facies computer model prior to completion of the first iteration of the simulation computer model.

18. The computer system of claim 17, wherein the constructing the simulation computer model is performed in parallel with performing the first iteration of the facies computer model by at least one electronic graphics processing unit.

19. The computer system of claim 11, wherein performing the first iteration of the simulation computer model further comprises constructing the wellbore and pipeline computer model prior to completion of the first iteration of the simulation computer model.

20. The computer system of claim 19, wherein the constructing the wellbore and pipeline computer model is performed in parallel with performing the first iteration of the simulation computer model by at least one electronic graphics processing unit.

1/6

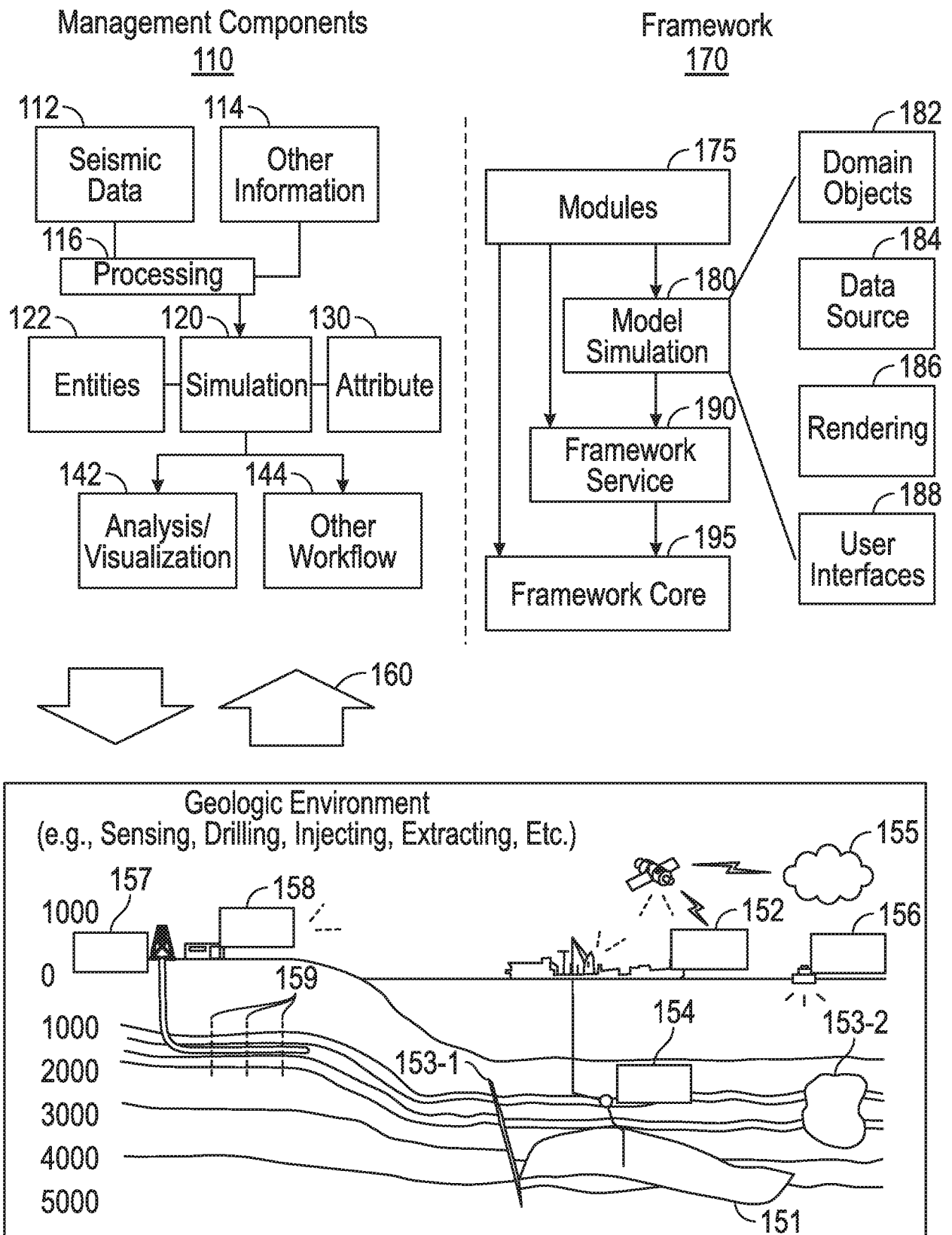


FIG. 1

2/6

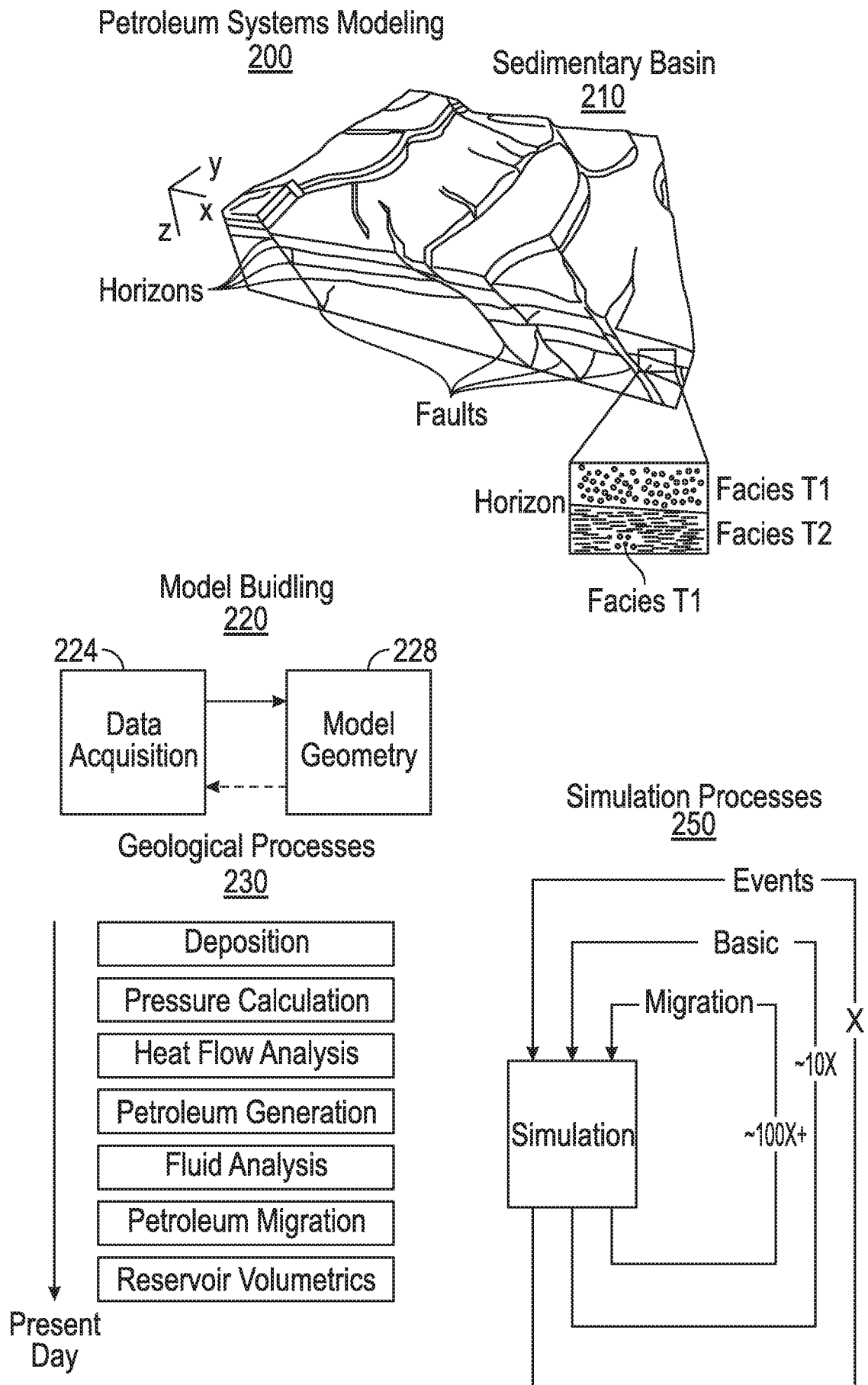


FIG. 2

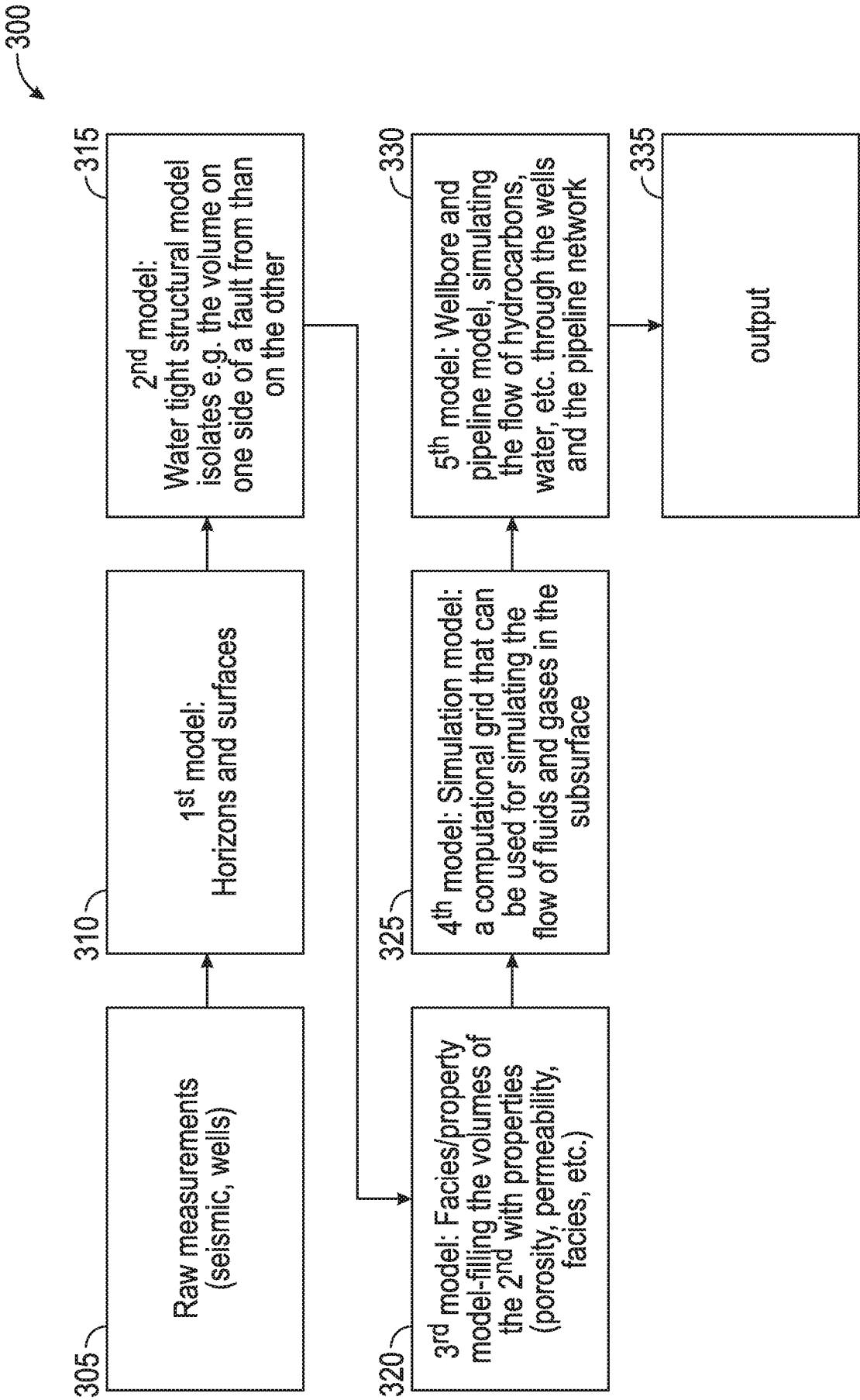


FIG. 3

4/6

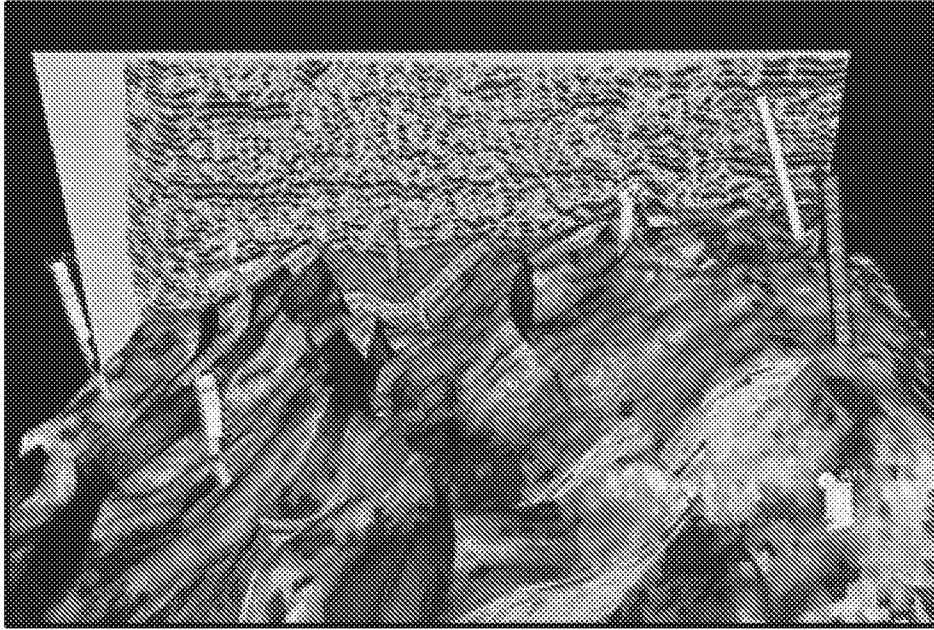


FIG. 4

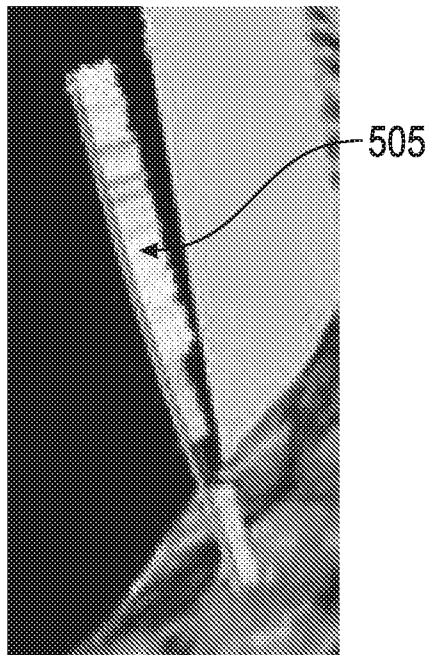


FIG. 5

5/6

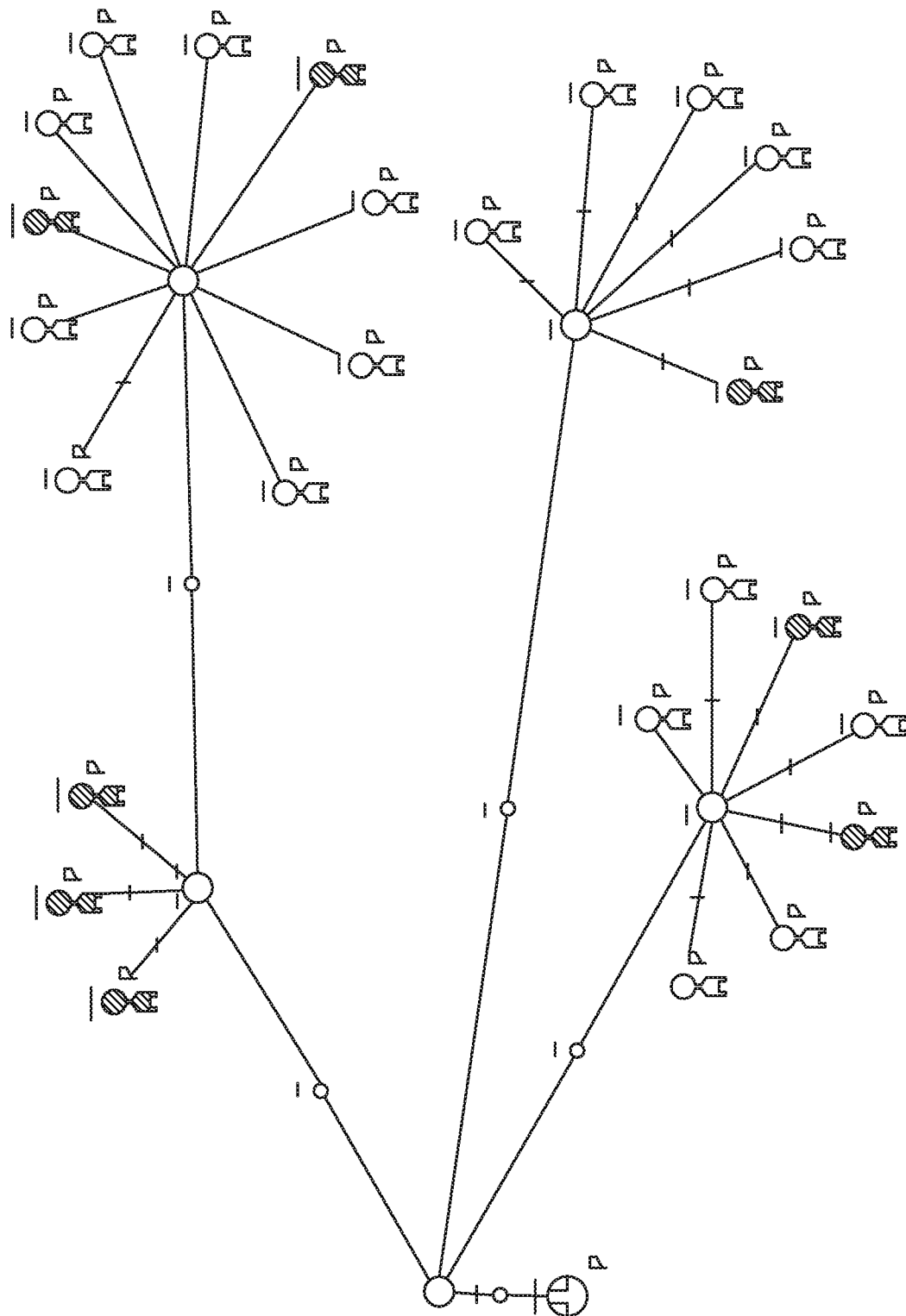


FIG. 6

6/6

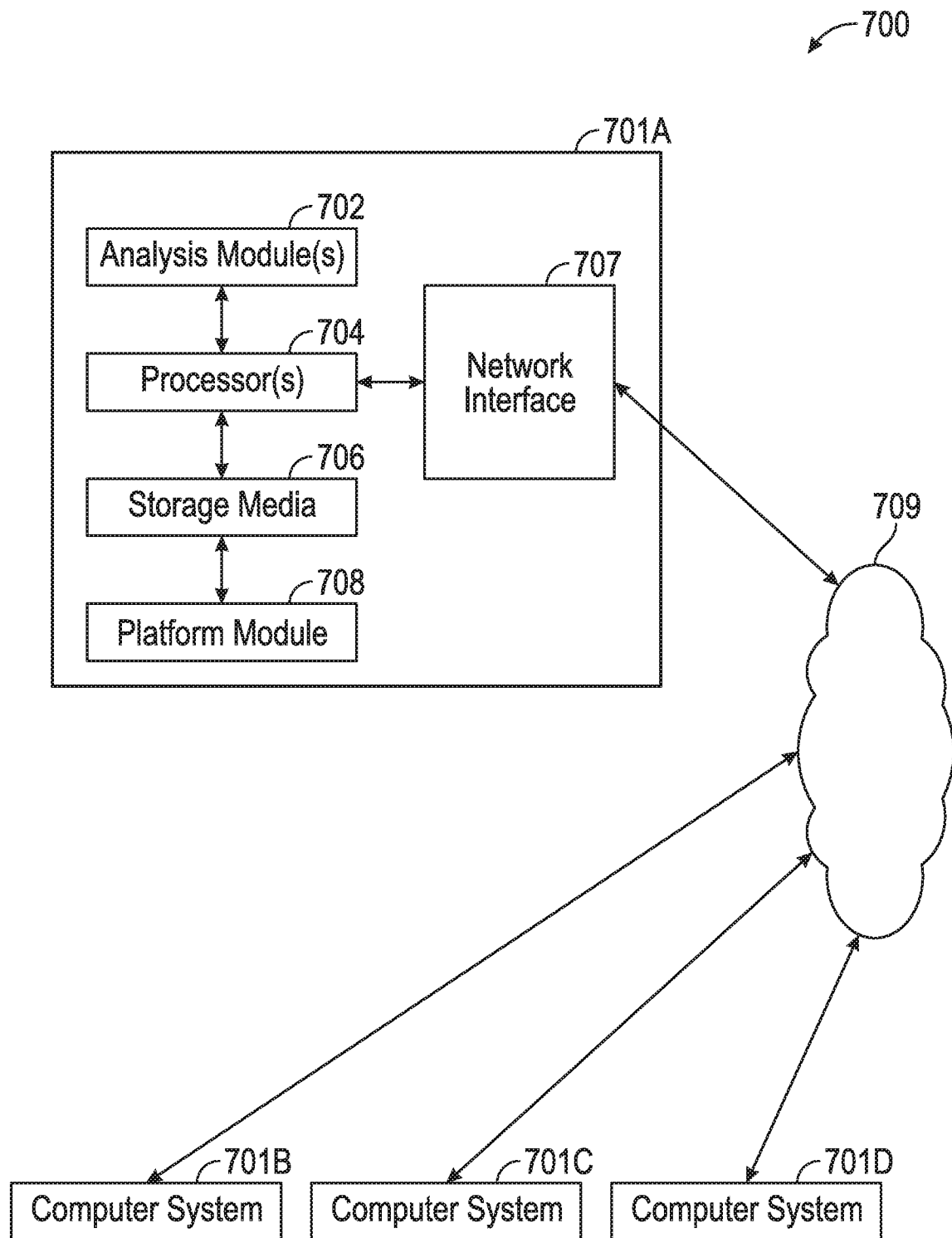


FIG. 7

A. CLASSIFICATION OF SUBJECT MATTER**G06F 17/50(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)

G06F 17/50; G06F 17/10; G06F 19/00; G06G 7/48; G06F 17/11; G06G 7/50; G01V 1/28; E21B 43/16; E21B 17/00

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: surface formation, modeling, geological, watertight volume, facies, flow, wellbore, pipeline, simulation, and similar terms.**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 7,742,875 B2 (DACHANG LI et al.) 22 June 2010	1,11
A	See column 6, line 7 - column 8, line 9; claim 1; and figure 2.	2-10,12-20
Y	US 2013-0132049 A1 (SAUDI ARABIAN OIL COMPANY) 23 May 2013	1,11
	See paragraph [0003] and claim 1.	
A	US 2011-0040533 A1 (RICHARD IAN TORRENS et al.) 17 February 2011	1-20
	See paragraphs [0028]-[0049] and figure 4.	
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Further documents are listed in the continuation of Box C.



See patent family annex.

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Name and mailing address of the ISA/KR

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INTERNATIONAL SEARCH REPORT

Information on patent family members

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