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(54) Title: METHOD AND SYSTEM FOR FRACTURING A FORMATION

(57) Abstract: Systems and methods are described for fracturing a production formation. A method includes drilling a well into a zone proximate to a production formation, and increasing a volume of the zone through the well in order to apply a mechanical stress to the production formation.



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METHOD AND SYSTEM FOR FRACTURING A FORMATION

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of U.S. Provisional Patent Application No. 61/407,249 filed October 27, 2010 entitled METHOD AND SYSTEM FOR FRACTURE STIMULATION, and also claims benefit to U.S. Provisional Application No. 61/544,757, filed October 7, 2011, entitled METHOD AND SYSTEM FOR FRACTURE STIMULATION BY CYCLIC FORMATION SETTLING AND DISPLACEMENT and U.S. Provisional Application No. 61/544,766, filed October 7, 2011 entitled METHOD AND SYSTEM FOR FRACTURE STIMULATION BY FORMATION DISPLACEMENT.

FIELD OF THE INVENTION

[0002] Embodiments of the present techniques relate to a method and system for fracture stimulation of subterranean formations to enhance the recovery of hydrocarbons. Specifically, an exemplary embodiment provides for creating fractures and other flow paths by delamination and rubblization of formations.

BACKGROUND

[0003] This section is intended to introduce various aspects of the art that may be topically associated with embodiments of the present techniques. This discussion is believed to assist in providing a framework to facilitate a better understanding of particular aspects of the present techniques. Accordingly, it should be understood that this section should be read in this light, and not necessarily as admissions of prior art.

[0004] As hydrocarbon reservoirs that are easily harvested, such as reservoirs on land or reservoirs located in shallow ocean water, are used up, other hydrocarbon sources must be used to keep up with energy demands. Such reservoirs may include any number of unconventional hydrocarbon sources, such as biomass, deep-water oil reservoirs, and natural gas from other sources.

[0005] One such unconventional hydrocarbon source is natural gas produced from formations that form unconventional gas reservoirs, including, for example, shale and coal seams. Because unconventional gas reservoirs may have insufficient permeability to allow significant fluid flow to a wellbore, many of such unconventional gas reservoirs are currently

not considered as practical sources of natural gas. However, natural gas has been produced for years from low permeability reservoirs having natural fractures. Furthermore, a significant increase in shale gas production has resulted from hydraulic fracturing, which can be used to create extensive artificial fractures around wellbores. When combined with
5 horizontal drilling, which is often used with wells in tight gas reservoirs, the hydraulic fracturing may allow formerly unpractical reservoirs to be commercially viable.

[0006] The fracturing process is complicated and often requires numerous hydraulic fractures in a single well and numerous wells for an economic field development. More efficient fracturing processes may provide a more productive reservoir. In other words, a
10 greater amount of the gas, or other hydrocarbon, trapped in a relatively non-porous reservoir, such as a tight gas, tight sand, shale layer or even a coal seam may be harvested. Accordingly, numerous researchers have explored ways to improve fracturing.

[0007] For example, U.S. Patent No. 3,455,391, to Matthews, et al., discloses a process for horizontally fracturing subterranean earth formations. The process is performed by
15 injecting a hot fluid at high pressure, until vertical fractures are formed and then closed due to thermal expansion of the earth formation. A fluid is then injected at a pressure sufficient to form horizontal fractures.

[0008] A similar process is disclosed in U.S. Patent No. 3,613,785, to Closman and Phocas. In this process a wellbore is extended into the formation and a vertical fracture is
20 generated by pressurizing the borehole. A hot fluid is injected into the formation to heat the formation, until thermal stressing of the formation matrix material causes the horizontal compressive stress in the formation to exceed the vertical compressive stress at a location selected for a second well. Hydraulically fracturing the formation through this second well can form a horizontal fracture extending into the formation.

25 [0009] Other approaches have focused on relieving stress in the formation, for example, by cavitation of the formation. For example, U.S. Patent No. 5,147,111, to Montgomery, discloses a method for cavity induced stimulation of coal degasification wells. The method can be used for improving the initial production of fluids, such as methane, from a coal seam. To perform the method, a well is drilled and completed into the seam. A tubing string is run
30 into the hole and liquid carbon dioxide is pumped down the tubing while a backpressure is maintained on the well annulus. The pumping is stopped, and the pressure is allowed to build until it reached a desired elevated pressure, for example, 1500 to 2000 psia. The pressure is quickly released, causing the coal to fail and fragment into particles. The particles are

removed to form a cavity in the seam. The cavity can allow expansion of the coal, potentially leading to opening of cleats within the coal seam.

[0010] A similar concept has been described in Ukraine Patent No. 35282, which discloses another method for coal degasification, but through subsurface gasification of an underburden coal seam (a coal seam that underlies the gas-containing formation). In this process, wellbores are drilled through an underburden coal bed so that a gasification catalyst can be applied. Once gasification occurs and lowers the underburden pressure due to depletion, subsidence of the overburden (e.g., the layer containing the gas) occurs due to gravitational loading. The subsidence can potentially create microfractures within the overburden reservoir, thereby allowing improved gas migration to the degassing wells.

[0011] It has also been noted that vertical wells and mining processes can lower stress points on coal seams, leading to increases in the production of coal bed methane. For example, S. Sang, et al., "Stress relief coalbed methane drainage by surface vertical wells in China," International Journal of Coal Geology, Volume 82, 196–203 (2010), presents a summary of studies on improved coalbed methane production by stress relief. The paper summarizes the status of engineering practice, technology, and research related to stress relief coalbed methane (CBM) drainage using surface wells in China during the past 10 years. Comments are provided on the theory and technical progress of this method. In high gas mining areas, such as the Huainan, Huaibei and Tiefsa mining areas, characterized by heavily sheared coals with relatively low permeability, stress relief CBM surface well drainage has been successfully implemented and has broad acceptance as a CBM exploitation technology. The fundamental theories underpinning stress relief CBM surface well drainage include elements relating to: (1) formation layer deformation theory, vertical zoning and horizontal partitioning, and the change in the stress condition in mining stopes; (2) a theory regarding an Abscission Circle in the development of mining horizontal abscission fracture and vertical broken fracture in overlaying formations; and (3) the theory of stress relief inducing permeability increase in protected coal seams during mining; and the gas migration–accumulation theory of stress relief CBM surface well drainage.

[0012] Other techniques for increasing production from coal beds, and other reservoirs, have focused on in-situ pyrolysis of hydrocarbons in a reservoir, followed by production of hydrocarbons from the reservoir. All of these techniques above have focused on the treatment of the hydrocarbon reservoir itself. Further, some techniques have taught that

relieving a stress on a reservoir may enhance the production of hydrocarbons, for example, by allowing cleats to open up in coal seams.

- [0013] Related information may be found in S.E. Laubach, et al., "Characteristics and origins of coal cleat: A review," International Journal of Coal Geology 35 (1998), 175-207;
- 5 Ian Palmer, "Coalbed methane completions: A world view," International Journal of Coal Geology 82 (2010), 184-195; Jack A. Pashin, "Stratigraphy and structure of coalbed methane reservoirs in the United States: An overview," International Journal of Coal Geology 35 (1998), 209-240; Pablo F. Sanz, et al., "Mechanical models of fracture reactivation and slip on bedding surfaces during folding of the asymmetric anticline at Sheep Mountain,
- 10 Wyoming," Journal of Structural Geology 30 (2008), 1177-1191; V. Palchik, "Localization of mining-induced horizontal fractures along formation layer interfaces in overburden: field measurements and prediction," Environ. Geol. 48 (2005), 68-80; and Stephen P. Laubach, et al., "Differential compaction of interbedded sandstone and coal," from: Cosgrove, J.W. and Ameen, M.S. (eds.), Forced Folds and Fractures, Geological Society of London, Special
- 15 Publications, 169, 51-60 (The Geological Society of London 2000).

SUMMARY

- [0014] An embodiment described herein provides a method for fracturing a production formation. The method includes drilling a well into a zone proximate to a production formation, and increasing a volume of the zone through the well in order to apply a
- 20 mechanical stress to the production formation.

- [0015] Another embodiment described herein provides a hydrocarbon production system. The system includes a hydrocarbon reservoir and a zone proximate to the hydrocarbon reservoir. The system also includes a stimulation well drilled to the zone and a stimulation system configured to create a volumetric change in the zone through the stimulation well. A
- 25 production well in the system is drilled to the hydrocarbon reservoir.

- [0016] Another embodiment described herein provides a method for harvesting hydrocarbons from a formation. The method includes drilling a production well in a production interval and drilling a stimulation well in a treatment interval. A volumetric change is caused in the treatment interval through the stimulation well, wherein the
- 30 volumetric change causes the formation of a fracture field in the production interval. The production well is completed to place the production well in contact with the fracture field and hydrocarbons are harvested from the production interval

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] The advantages of the present techniques are better understood by referring to the following detailed description and the attached drawings, in which:

[0018] Fig. 1 is a diagram of a hydraulic fracturing process;

5 [0019] Fig. 2 is a drawing of a local stress state for an element in a hydrocarbon bearing subterranean formation;

[0020] Fig. 3 is a drawing of a first mode (mode 1) of fracture formation, commonly resulting from a standard hydraulic fracturing process;

10 [0021] Fig. 4 is an exemplified drawing of a well treatment system such as a hydraulic fracturing system, wherein a zone below a hydrocarbon bearing subterranean formation is subjected to a volumetric expansion, which can place stress on the hydrocarbon bearing subterranean formation leading to fracturing;

[0022] Fig. 5 is a block diagram of a method for stimulation of a hydrocarbon bearing subterranean formation by treating a formation outside of the reservoir;

15 [0023] Fig. 6 is a more detailed schematic view of a delamination fracture stimulation showing the physics that may lead to delamination fracturing;

[0024] Fig. 7 is a drawing of two modes of sliding fracture formation that may participate in delamination fracture stimulation as discussed herein;

20 [0025] Fig. 8 is a drawing of rubblization during shearing at a fracture interface or boundary;

[0026] Fig. 9 is a drawing of an azimuthal rotation of fracture planes within a formation that may occur as a result of cyclic treatment of the formation;

[0027] Fig. 10 is a drawing of a vertical well passing through a reservoir interval and a treatment interval, in which a notch has been formed in the treatment interval;

25 [0028] Fig. 11 is a drawing of the stress distribution in the formation around the tip of a notch;

[0029] Figs. 12(A)-(D) are drawings of a number of well configurations that can be used in embodiments of the techniques described herein;

30 [0030] Figs. 13(A)-(F) are drawings of a series of branched wells that can use the configurations discussed with respect to Figs. 12(B) and (D); and

[0031] Fig. 14 is a drawing of a stacked treatments technique that may be useful for increasing the effects of the treatment of a zone on the hydrocarbon bearing subterranean formation.

DETAILED DESCRIPTION

5 [0032] In the following detailed description section, the specific embodiments of the present techniques are described in connection with exemplary embodiments. However, to the extent that the following description is specific to a particular embodiment or a particular use of the present techniques, this is intended to be for exemplary purposes only and simply provides a description of the exemplary embodiments. Accordingly, the present techniques
10 are not limited to the specific embodiments described below, but rather, such techniques include all alternatives, modifications, and equivalents falling within the true spirit and scope of the appended claims.

[0033] At the outset, and for ease of reference, certain terms used in this application and their meanings as used in this context are set forth. To the extent a term used herein is not
15 defined below, it should be given the broadest definition persons in the pertinent art have given that term as reflected in at least one printed publication or issued patent. Further, the present techniques are not limited by the usage of the terms shown below, as all equivalents, synonyms, new developments, and terms or techniques that serve the same or a similar purpose are considered to be within the scope of the present claims.

20 [0034] The “Bulk modulus” of a rock sample from a formation relates the pressure to the volume change given by the dilation ϵ_{kk} . It is an elastic property of the material and is usually denoted by the English alphabet K having units the same as that of stress, and is given by:

$$K = \frac{3\lambda + 2\mu}{3}.$$

25 [0035] “Cavitation completion” or “cavitation” is a process by which an opening may be made in a formation. Generally, cavitation is performed by drilling a well into a formation. The formation is then pressurized in the vicinity of the well. The pressure is suddenly released, causing the material in the vicinity of the well to fragment. The fragments and debris may then be swept to the surface through the well by circulating a fluid through the
30 well.

[0036] “Cleat system” is the system of naturally occurring joints that are created as a coal seam forms over geologic time. A cleat system allows for the production of natural gas if the provided permeability to the coal seam is sufficient.

5 [0037] “Coal” is a solid hydrocarbon, including, but not limited to, lignite, sub-bituminous, bituminous, anthracite, peat, and the like. The coal may be of any grade or rank. This can include, but is not limited to, low grade, high sulfur coal that is not suitable for use in coal-fired power generators due to the production of emissions having high sulfur content.

10 [0038] “Coalbed methane” (CBM) is a natural gas that is adsorbed onto the surface of coal. CBM may be substantially comprised of methane, but may also include ethane, propane, and other hydrocarbons. Further, CBM may include some amount of other gases, such as carbon dioxide (CO₂) and nitrogen (N₂).

15 [0039] A “compressor” is a machine that increases the pressure of a gas by the application of work (compression). Accordingly, a low pressure gas (for example, 5 psig) may be compressed into a high-pressure gas (for example, 1000 psig) for transmission through a pipeline, injection into a well, or other processes.

20 [0040] “Directional drilling” is the intentional deviation of the wellbore from the path it would naturally take. In other words, directional drilling is the steering of the drill string so that it travels in a desired direction. Directional drilling can be used for increasing the drainage of a particular well, for example, by forming deviated branch bores from a primary borehole. Directional drilling is also useful in the marine environment where a single offshore production platform can reach several hydrocarbon bearing subterranean formations or reservoirs by utilizing a plurality of deviated wells that can extend in any direction from the drilling platform. Directional drilling also enables horizontal drilling through a reservoir to form a horizontal wellbore. As used herein, “horizontal wellbore” represents the portion of
25 a wellbore in a subterranean zone to be completed which is substantially horizontal or at an angle from vertical in the range of from about 15° to about 75°. A horizontal wellbore may have a longer section of the wellbore traversing the payzone of a reservoir, thereby permitting increases in the production rate from the well.

30 [0041] “Exemplary” is used exclusively herein to mean “serving as an example, instance, or illustration.” Any embodiment described herein as exemplary is not to be construed as preferred or advantageous over other embodiments.

[0042] A “facility” is tangible piece of physical equipment, or group of equipment units, through which hydrocarbon fluids are either produced from a reservoir or injected into a reservoir. In its broadest sense, the term facility is applied to any equipment that may be present along the flow path between a reservoir and its delivery outlets, which are the
5 locations at which hydrocarbon fluids either leave the model (produced fluids) or enter the model (injected fluids). Facilities may comprise production wells, injection wells, well tubulars, wellhead equipment, gathering lines, manifolds, pumps, compressors, separators, surface flow lines, and delivery outlets. In some instances, the term “surface facility” is used to distinguish those facilities other than wells.

10 [0043] As used herein, the force “F” could be compressional, leading to longitudinally compressing the strength member, or tensional, leading to longitudinally extending the strength member. In the case of a strength member in a seismic section, the force will typically be tension.

[0044] “Formation” refers to a body or section of geologic strata, structure, formation, or
15 other subsurface solids or collected material that is sufficiently distinctive and continuous with respect to other geologic strata or other characteristics that it can be mapped, for example, by seismic techniques. A formation can be a body of geologic strata of predominantly one type of rock or a combination of types of rock, or a fraction of strata having substantially common set of characteristics. A formation can contain one or more
20 hydrocarbon-bearing subterranean formations. Note that the terms formation, hydrocarbon bearing subterranean formation, reservoir, and interval may be used interchangeably, but may generally be used to denote progressively smaller subsurface regions, zones, or volumes. More specifically, a geologic formation may generally be the largest subsurface region, a hydrocarbon reservoir or subterranean formation may generally be a region within the
25 geologic formation and may generally be a hydrocarbon-bearing zone, a formation, reservoir, or interval having oil, gas, heavy oil, and any combination thereof. An interval or production interval may generally refer to a sub-region or portion of a reservoir. A hydrocarbon-bearing zone, or production formation, may be separated from other hydrocarbon-bearing zones by zones of lower permeability such as mudstones, shales, or shale-like (highly compacted)
30 sands. In one or more embodiments, a hydrocarbon-bearing zone may include heavy oil in addition to sand, clay, or other porous solids.

[0045] A “fracture” is a crack, delamination, surface breakage, separation, crushing, rubblization, or other destruction within a geologic formation or fraction of formation that is

not related to foliation or cleavage in metamorphic formation, along which there has been displacement or movement relative to an adjacent portion of the formation. A fracture along which there has been lateral displacement may be termed a fault. When walls of a fracture have moved only normal to each other, the fracture may be termed a joint. Fractures may
5 enhance permeability of rocks greatly by connecting pores together, and for that reason, joints and faults may be induced mechanically in some reservoirs in order to increase fluid flow.

[0046] “Fracturing” refers to the structural degradation of a treatment interval, such as a subsurface shale formation, from applied thermal or mechanical stress. Such structural
10 degradation generally enhances the permeability of the treatment interval to fluids and increases the accessibility of the hydrocarbon component to such fluids. Fracturing may also be performed by degrading rocks in treatment intervals by chemical means. “Fracture network” refers to a field or network of interconnecting fractures, usually formed during hydraulic fracturing. A “fracture field” is a group of fractures, which may or may not be
15 interconnected, and are created by a single fracturing event, such as by a volumetric change in a zone proximate to a target formation, which fractures the target formation.

[0047] “Fracture gradient” refers to an equivalent fluid pressure sufficient to create or enhance one or more fractures in the subterranean formation. As used herein, the “fracture gradient” of a layered formation also encompasses a parting fluid pressure sufficient to
20 separate one or more adjacent bedding planes in a layered formation. It should be understood that a person of ordinary skill in the art could perform a simple leak-off test on a core sample of a formation to determine the fracture gradient of a particular formation.

[0048] “Geomechanical stress” or “stress” including a change related thereto, or similar phrase, refers generally to the forces external to or interior to a formation acting upon or
25 within such formation. The forces may define a stress state, condition, or property of a formation, zone, or other geologic strata, and/or any fluid contained therein. In embodiments, the stress state may be manipulated to control the creation of fractures in particular directions.

[0049] “Heat source” is any system for providing heat to at least a portion of a formation substantially by conductive or radiative heat transfer. For example, a heat source may
30 include electric heaters such as an insulated conductor, an elongated member, or a conductor disposed in a conduit. Other heating systems may include electric resistive heaters placed in wells, electrical induction heaters placed in wells, circulation of hot fluids through wells, resistively heated conductive propped fractures emanating from wells, downhole burners,

exothermic chemical reactions, and in situ combustion. A heat source may also include systems that generate heat by burning a fuel external to or in a formation. The systems may be surface burners, downhole gas burners, flameless distributed combustors, and natural gas distributed combustors. In some embodiments, heat provided to or generated in one or more
5 heat sources may be supplied by other sources of energy. The other sources of energy may directly heat a formation, or the energy may be applied to a transfer medium that directly or indirectly heats the formation. For example, an “electrofrac heater” may use electrical conductive propped fractures to apply heat to the formation. In an electrofrac heater, a formation is hydraulically fractured and a graphite proppant is used to prop the fractures
10 open. An electric current may then be passed through the graphite proppant causing it to generate heat, which heats the surrounding formation.

[0050] “Hydraulic fracturing” is used to create single or branching fractures that extend from the wellbore into reservoir formations so as to stimulate the potential for production. A fracturing fluid, typically a viscous fluid, is injected into the formation with sufficient
15 pressure to create and extend a fracture, and a proppant is used to “prop” or hold open the created fracture after the hydraulic pressure used to generate the fracture has been released. When pumping of the treatment fluid is finished, the fracture “closes.” Loss of fluid to a permeable formation results in a reduction in fracture width until the proppant supports the fracture faces. The fracture may be artificially held open by injection of a proppant material.
20 Hydraulic fractures may be substantially horizontal in orientation, substantially vertical in orientation, or oriented along any other plane. Generally, the fractures tend to be vertical at greater depths, due to the increased magnitude of the vertical stress relative to the horizontal stresses. As used herein, fracturing may take place in portions of a formation outside of a hydrocarbon bearing subterranean formation in order to enhance hydrocarbon production
25 from the hydrocarbon bearing subterranean formation.

[0051] “Hydrocarbon production” refers to any activity associated with extracting hydrocarbons from a well or other opening. Hydrocarbon production normally refers to any activity conducted in or on the well after the well is completed. Accordingly, hydrocarbon production or extraction includes not only primary hydrocarbon extraction but also secondary
30 and tertiary production techniques, such as injection of gas or liquid for increasing drive pressure, mobilizing the hydrocarbon or treating by, for example chemicals or hydraulic fracturing the wellbore to promote increased flow, well servicing, well logging, and other well and wellbore treatments.

[0052] “Hydrocarbons” are generally defined as molecules formed primarily of carbon and hydrogen atoms such as oil and natural gas. Hydrocarbons may also include other elements, such as, but not limited to, halogens, metallic elements, nitrogen, oxygen, and/or sulfur. Hydrocarbons may be produced from hydrocarbon bearing subterranean formations through wells penetrating a hydrocarbon containing formation. Hydrocarbons derived from a hydrocarbon bearing subterranean formation may include, but are not limited to, kerogen, bitumen, pyrobitumen, asphaltenes, oils, natural gas, or combinations thereof. Hydrocarbons may be located within or adjacent to mineral matrices within the earth. Matrices may include, but are not limited to, sedimentary rock, sands, silicilytes, carbonates, diatomites, and other porous media.

[0053] A “hydraulic fracture” is a fracture at least partially propagated into a formation, wherein the fracture is created through injection of pressurized fluids into the formation. While the term “hydraulic fracture” is used, the techniques described herein are not limited to use in hydraulic fractures. The techniques may be suitable for use in any fractures created in any manner considered suitable by one skilled in the art. Hydraulic fractures may be substantially horizontal in orientation, substantially vertical in orientation, or oriented along any other plane. Generally, the fractures tend to be vertical at greater depths, due to the increased magnitude of the vertical stress relative to the horizontal stresses.

[0054] “Ideally elastic” refers to a material in which a body formed of the material recovers its original form completely upon removal of the forces causing the deformation, and a material that has a one-to-one, i.e., unique relationship between the state of stress and the state of strain at a given temperature. For many materials, strain is directly proportional to the stress, at least at stresses below the yield strength of a material. This linear relationship between strain ϵ_{ij} and stress σ_{ij} occurring at stresses below the yield strength is known as the generalized Hooke's law, and is represented by the formula:

$$\sigma_{ij} = C_{ijkl} \epsilon_{kl}$$

where summation convention is employed, meaning that in Cartesian coordinates whenever the same letter subscript occurs twice in a term, that subscript is to be given all possible values and the results added together, and here i,j,k,l each take the values 1,2,3. The 9 equations represented above contain 81 elastic constants, C_{ijkl} , but symmetry of the stress tensor, σ_{ij} , and existence of a strain energy function reduce the number of distinct constants to 21. A “plane of elastic symmetry” is a plane in which the elastic constants at a point have

the same values for every pair of coordinate systems which are mirror images of each other in a certain plane.

[0055] “Imbibition” refers to the incorporation of a fracturing fluid into a fracture face by capillary action. Imbibition may result in decreases in permeation of a formation fluid across the fracture face, and is known to be a form of formation damage. For example, if the fracturing fluid is an aqueous fluid, imbibition may result in lower transport of organic materials, such as hydrocarbons, across the fracture face, resulting in decreased recovery. The decrease in hydrocarbon transport may outweigh any increases in fracture surface area resulting in no net increase in recovery, or even a decrease in recovery, after fracturing.

10 [0056] “In-Situ” or “insitu” refers to a state, condition, or property of a geologic formation, strata, zone, and/or fluids therein, prior to changing or altering such state, condition, or property by an action affecting the formation and/or fluids therein. Changes to the insitu properties may be effected by substantially any action upon the formation, such as producing or removing fluids from a formation, injecting or introducing fluids or other materials into a formation, stimulating a formation, causing a collapse such as permitting a wellbore collapse or dissolving supporting strata, removing adjacent formation or fluid, heating or cooling the formation, or other action that effects change in the state, condition or property of the formation. The insitu state may or may not be the virgin or original state of the formation, but is a relative term that may in fact merely reference a state that exists prior to undertaking some action upon the formation.

[0057] An “isotropic” material is one in which the body’s elastic constants, C_{ijkl} , are the same in every set of reference axes at any point for a given situation. For a such a material, the number of distinct elastic constants is two, and the strains can be related to the stresses by Hooke’s Law:

$$25 \quad \sigma_{ij} = \lambda \delta_{ij} \varepsilon_{kk} + 2\mu \varepsilon_{ij},$$

where the distinct elastic constants are λ and μ , the Lamé constants. μ is also known as the “modulus of rigidity” or “shear modulus” and is sometimes expressed as G. Three additional constants, E, K, and ν can be defined as combinations of the Lamé constants.

[0058] As used herein, “material properties” represents any number of physical constants that reflect the behavior of a rock. Such material properties may include, for example, Young’s modulus (E), Poisson’s Ratio (ν), tensile strength, compressive strength, shear strength, creep behavior, and other properties. The material properties may be measured by

any combinations of tests, including, among others, a “Standard Test Method for Unconfined Compressive Strength of Intact Rock Core Specimens,” ASTM D 2938-95; a “Standard Test Method for Splitting Tensile Strength of Intact Rock Core Specimens [Brazilian Method],” ASTM D 3967-95a Reapproved 1992; a “Standard Test Method for Determination of the Point Load Strength Index of Rock,” ASTM D 5731-95; “Standard Practices for Preparing Rock Core Specimens and Determining Dimensional and Shape Tolerances,” ASTM D 4435-01; “Standard Test Method for Elastic Moduli of Intact Rock Core Specimens in Uniaxial Compression,” ASTM D 3148-02; “Standard Test Method for Triaxial Compressive Strength of Undrained Rock Core Specimens Without Pore Pressure Measurements,” ASTM D 2664-04; “Standard Test Method for Creep of Cylindrical Soft Rock Specimens in Uniaxial Compressions,” ASTM D 4405-84, Reapproved 1989; “Standard Test Method for Performing Laboratory Direct Shear Strength Tests of Rock Specimens Under Constant Normal Stress,” ASTM D 5607-95; “Method of Test for Direct Shear Strength of Rock Core Specimen,” U.S. Military Rock Testing Handbook, RTH-203-80, available at “<http://www.wes.army.mil/SL/MTC/handbook/RT/RTH/203-80.pdf>” (last accessed on October 1, 2010); and “Standard Method of Test for Multistage Triaxial Strength of Undrained Rock Core Specimens Without Pore Pressure Measurements,” U.S. Military Rock Testing Handbook, available at <http://www.wes.army.mil/SL/MTC/handbook/RT/RTH/204-80.pdf> (last accessed on June 25, 2010). One of ordinary skill will recognize that other methods of testing rock specimens from formations may be used to determine the physical constants used herein.

[0059] “Natural gas” refers to various compositions of raw or treated hydrocarbon gases. Raw natural gas is primarily comprised of light hydrocarbons such as methane, ethane, propane, butanes, pentanes, hexanes and impurities like benzene, but may also contain small amounts of non-hydrocarbon impurities, such as nitrogen, hydrogen sulfide, carbon dioxide, and traces of helium, carbonyl sulfide, various mercaptans, or water. Treated natural gas is primarily comprised of methane and ethane, but may also contain small percentages of heavier hydrocarbons, such as propane, butanes, and pentanes, as well as small percentages of nitrogen and carbon dioxide.

[0060] An “orthotropic” material is one that has three symmetry planes and nine independent elastic constants if a strain-energy function exists. If the principal axes of strain coincide with the symmetry axes, then so do the principal axes of stress.

[0061] “Overburden” refers to the subsurface formation overlying the formation containing one or more hydrocarbon-bearing zones (the reservoirs). For example, overburden may include rock, shale, mudstone, or wet/tight carbonate (such as an impermeable carbonate without hydrocarbons). An overburden may include a hydrocarbon-
5 containing layer that is relatively impermeable. In some cases, the overburden may be permeable.

[0062] “Overburden stress” refers to the load per unit area or stress overlying an area or point of interest in the subsurface from the weight of the overlying sediments and fluids. In one or more embodiments, the “overburden stress” is the load per unit area or stress overlying
10 the hydrocarbon-bearing zone that is being conditioned or produced according to the embodiments described. In general, the magnitude of the overburden stress may primarily depend on two factors: 1) the composition of the overlying sediments and fluids, and 2) the depth of the subsurface area or formation. Similarly, underburden refers to the subsurface formation underneath the formation containing one or more hydrocarbon-bearing zones
15 (reservoirs).

[0063] “Permeability” is the capacity of a formation to transmit fluids through the interconnected pore spaces of the rock. Permeability may be measured using Darcy's Law: $Q = (k \Delta P A) / (\mu L)$, where Q = flow rate (cm^3/s), ΔP = pressure drop (atm) across a cylinder having a length L (cm) and a cross-sectional area A (cm^2), μ = fluid viscosity (cp), and k =
20 permeability (Darcy). The customary unit of measurement for permeability is the millidarcy. The term “relatively permeable” is defined, with respect to formations or portions thereof, as an average permeability of 10 millidarcy or more (for example, 10 or 100 millidarcy). The term “relatively low permeability” is defined, with respect to formations or portions thereof, as an average permeability of less than about 10 millidarcy. An impermeable layer generally
25 has a permeability of less than about 0.1 millidarcy. By these definitions, shale may be considered impermeable, for example, ranging from about 0.1 millidarcy (100 microdarcy) to as low as 0.00001 millidarcy (10 nanodarcy).

[0064] “Porosity” is defined as the ratio of the volume of pore space to the total bulk volume of the material expressed in percent. Although there often is an apparent close
30 relationship between porosity and permeability, because a highly porous formation may be highly permeable, there is no real relationship between the two; a formation with a high percentage of porosity may be very impermeable because of a lack of communication between the individual pores, capillary size of the pore space or the morphology of structures

constituting the pore space. For example, the diatomite in one exemplary rock type found in formations, Belridge, has very high porosity, at about 60%, but the permeability is very low, for example, less than about 0.1 millidarcy.

- [0065] The “Poisson’s ratio” of a rock sample from a formation is the ratio of a unit of lateral contraction to a unit of longitudinal extension for tension. It is a dimensionless elastic property of the material and is usually denoted by the Greek alphabet ν , and is given by:

$$\nu = \frac{\lambda}{2(\lambda + \mu)}.$$

- [0066] “Pressure” refers to a force acting on a unit area. Pressure is usually shown as pounds per square inch (psi). “Atmospheric pressure” refers to the local pressure of the air. Local atmospheric pressure is assumed to be 14.7 psia, the standard atmospheric pressure at sea level. “Absolute pressure” (psia) refers to the sum of the atmospheric pressure plus the gauge pressure (psig). “Gauge pressure” (psig) refers to the pressure measured by a gauge, which indicates only the pressure exceeding the local atmospheric pressure (a gauge pressure of 0 psig corresponds to an absolute pressure of 14.7 psia).

- [0067] As previously mentioned, a “reservoir” or “hydrocarbon reservoir” is defined as a pay zone or production interval (for example, a hydrocarbon bearing subterranean formation) that includes sandstone, limestone, chalk, coal, and some types of shale. Pay zones can vary in thickness from less than one foot (0.3048 m) to hundreds of feet (hundreds of m). The permeability of the reservoir formation provides the potential for production.

- [0068] “Reservoir properties” and “Reservoir property values” are defined as quantities representing physical attributes of rocks containing reservoir fluids. The term “reservoir properties” as used in this application includes both measurable and descriptive attributes. Examples of measurable reservoir property values include impedance to P-waves, impedance to S-waves, porosity, permeability, water saturation, and fracture density. Examples of descriptive reservoir property values include facies, lithology (for example, sandstone or carbonate), and environment-of-deposition (EOD). Reservoir properties may be populated into a reservoir framework of computational cells to generate a reservoir model.

- [0069] A “rock physics model” relates petrophysical and production-related properties of a formation (or its constituents) to the bulk elastic properties of the formation. Examples of petrophysical and production-related properties may include, but are not limited to, porosity, pore geometry, pore connectivity volume of shale or clay, estimated overburden stress or

related data, pore pressure, fluid type and content, clay content, mineralogy, temperature, and anisotropy and examples of bulk elastic properties may include, but are not limited to, P-impedance and S-impedance. A rock physics model may provide values that may be used as a velocity model for a seismic survey.

5 [0070] “Shale” is a fine-grained clastic sedimentary rock that may be found in formations, and may often have a mean grain size of less than 0.0625 mm. Shale typically includes laminated and fissile siltstones and claystones. These materials may be formed from clays, quartz, and other minerals that are found in fine-grained rocks. Non-limiting examples of shales include Barnett, Fayetteville, and Woodford in North America. Shale has low
10 matrix permeability, so gas production in commercial quantities requires fractures to provide permeability. Shale gas reservoirs may be hydraulically fractured to create extensive artificial fracture networks around wellbores. Horizontal drilling is often used with shale gas wells.

[0071] “Stimulated Rock Volume” (SRV) describes a relatively large formation volume
15 that has experienced increased permeability and associated hydrocarbon production potential through the use of changed in-situ stress (either applied or reduced stress) and strain techniques, such as but not limited to hydraulic fracturing or other related reservoir stimulation or stressing techniques. In one potential SRV scenario, a network of hydraulic fractures could be in communication with fractures that naturally occur in the formation so
20 that the formation volume outside of one specific hydraulic fracture experiences improved reservoir properties.

[0072] “Strain” is the fractional change in dimension or volume of the deformation induced in the material by applying stress. Strain is usually denoted by the Greek alphabet ϵ . The nine components which fully define the strain at a given point are expressed as ϵ_{ij} ,
25 where i, j , each take the values 1,2,3.

[0073] “Stress” is the application of force to a material, such as a through a hydraulic fluid used to fracture a formation. Stress can be measured as force per unit area. Thus, applying a longitudinal force f to a cross-sectional area S of a strength member yields a stress which is given by f/S . The force f could be compressional, leading to longitudinally
30 compressing the strength member, or tensional, leading to longitudinally extending the strength member. Stress is usually denoted by the Greek alphabet σ . The nine components which fully define the stress state at a given point are expressed as σ_{ij} , where i, j , each take the values 1,2,3.

[0074] “Substantial” when used in reference to a quantity or amount of a material, or a specific characteristic thereof, refers to an amount that is sufficient to provide an effect that the material or characteristic was intended to provide. The exact degree of deviation allowable may in some cases depend on the specific context.

- 5 [0075] “Thermal fractures” are fractures created in a formation caused by expansion or contraction of a portion of the formation or fluids within the formation. The expansion or contraction may be caused by changing the temperature of the formation or fluids within the formation. The change in temperature may change the pressure of fluids within the formation, resulting in the fracturing. Thermal fractures may propagate into or form in
10 neighboring regions significantly cooler than the heated zone.

[0076] “Tight oil” is used to reference formations with relatively low matrix permeability, porosity, or both, where liquid hydrocarbon production potential exists. In these formations, liquid hydrocarbon production may also include natural gas condensate.

- [0077] “Underburden” refers to the subsurface formation below or farther downhole than
15 a formation containing one or more hydrocarbon-bearing zones, e.g., a hydrocarbon reservoir. For example, underburden may include rock, shale, mudstone, or a wet/tight carbonate, such as an impermeable carbonate without hydrocarbons. An underburden may include a hydrocarbon-containing layer that is relatively impermeable. In some cases, the underburden may be permeable. The underburden may be a formation that is distinct from the
20 hydrocarbon bearing formation or may be a selected fraction within a common formation shared between the underburden portion and the hydrocarbon bearing portion. Intermediate layers may also reside between the underburden layer and the hydrocarbon bearing zone.

- [0078] The “Young’s modulus” of a rock sample from a formation is the stiffness of the rock sample, defined as the amount of axial load (or stress) sufficient to make the rock
25 sample undergo a unit amount of deformation (or strain) in the direction of load application, when deformed within its elastic limit. The higher the Young’s modulus, the more stress is required to deform it. It is an elastic property of the material and is usually denoted by the English alphabet E having units the same as that of stress, and is given by:

$$E = \frac{\mu(3\lambda + 2\mu)}{\lambda + \mu}.$$

Overview

[0079] Embodiments of the present techniques provide well completions and methods for stimulation of hydrocarbon bearing subterranean formations, or portions thereof, on a large scale, up to stimulating an entire formation at once. The methods include fracturing a
5 subterranean formation by applying stress in a zone proximate to the subterranean formation to indirectly translate a mechanical stress to the subterranean formation and affect a permeability increase within the subterranean formation. In embodiments, the desired permeability increase is effected by creation of a fracture field in the subterranean formation, such as by delamination fracturing during uplifting, down-folding or other affected
10 movement of the subterranean formation. The desired permeability may also be the result of other types of fracturing, but it is noted that for simplification purposes, all such fracturing and displacements may be referred to herein generally as fracturing.

[0080] The techniques may be used with any type of hydrocarbon bearing subterranean formation, such as oil, gas, or mixed reservoirs and may also be used to fracture other types
15 of formations, such as formations used for the production of geothermal energy. In exemplary embodiments, the techniques can be used to enhance production of natural gas from unconventional, e.g., low permeability, gas reservoirs.

[0081] In embodiments described herein a single wellbore may be used to reach both the zone proximate and the hydrocarbon bearing subterranean formation, or separate wellbores
20 may be used for access to each of the zone proximate and the subterranean formation. Similarly, a set of wells may be used for application of the principles and methods disclosed and provided herein, such as in a field-wide plan that utilizes numerous wellbores to effect the techniques provided herein. The inventive methods and systems provided herein may also be applied using any of a variety of wellbore configurations, such as substantially
25 vertical wells, horizontal wells, multi-branch wells, deviated wellbores, and combinations thereof. Well completions that may be used in embodiments are discussed further with respect to Figs. 11 and 12.

[0082] In embodiments, the stress on the zone proximate to the target formation may be applied by increasing a volume of the zone proximate. For example, a volumetric increase
30 may be created in the zone proximate by introducing a stress-inducing force into the zone proximate, such as via hydraulic fluid, explosively generated gases or pressure, thermal expansion, proppant or cuttings introduction, or other means of affecting such forces. The introduced force may be residual and long lasting or maintained such as via hydraulic fluid

introduction, or short in duration such as via explosives. Either such action may introduce residual volume increases, even though at least a portion of the volume increase may be lost when the force is removed. The action in the zone proximate is then translated or transferred into the objective formation, the subterranean formation, whereby a fracture field is created within the subterranean formation.

[0083] In embodiments, the stress on the zone proximate to the target formation may be applied by decreasing a volume of the zone proximate. The decrease in the volume of the zone proximate may effect a reduction in structural support within the zone proximate. This reduction in structural support translates into a corresponding reduction in stability of the hydrocarbon bearing subterranean formation, resulting in creation of a fracture field within the subterranean formation. Examples of effecting a stress reduction in the zone proximate may include freshwater dissolution of salt from a zone proximate, production of water or other fluids from a zone proximate to reduce structural support in the subterranean formation, chemical dissolution of the rock material within the zone proximate, physical removal of portion of the zone proximate, such as via a network of relatively large or under-reamed wellbores within the zone proximate, and similar actions or treatments to reduce structural strength of the zone proximate with respect to the in-situ, pre-treatment, or pre-action strength.

[0084] Further, the changes in the stress of the zone proximate do not have to involve a volumetric change. The methods described herein may include any number of other techniques that alter the geomechanical stresses of a formation, including external or internal stresses, by dislocation, displacement, strain changes, or fracturing of a zone proximate or subterranean formation, without substantial volumetric change therein. Although a volumetric change is not necessarily involved, the stress can still be communicated from the zone proximate to the targeted subterranean formation. The techniques described herein generally include treating a zone proximate to a target formation to effect a stress change in the zone proximate, which will effect a permeability increase in the target formation.

[0085] Further, the application of the stress, e.g., through volumetric changes, does not have to be performed as a single event. In some embodiments, application and removal of the stress and strain on the zone proximate may be cycled to cause subsequent rubblization and fracturing within the subterranean formation. The increased rubblization at fracture surfaces can lead to further improvements in permeability within the targeted formation.

[0086] The stress applied to the targeted formation can cause delamination of layers and other forms of non-hydraulic fracturing, leading to the formation of cracks over a broad area. The cracks or fractures may result from a residual or “hysteresis” displacement of the formation components due to the strain displacement that remains, both while the stress is applied and after the stress is relaxed. The hysteresis effect results from the failure of the crack or fracture to heal completely, in the event further fracturing happens and/or the applied stress is reduced. Thereby, the permeability may be at least somewhat permanently improved. Ideally, the stress applied to the target formation creates some residual permeability in at least a portion of the targeted subterranean formation. The treatment duration may range from seconds, such as if explosives are used, to a period of months, such as if waste tailings are used to fracture and prop open the fractures in the zone proximate formation.

[0087] At the delaminated fractures, the formation surfaces or rock strata within the formation can be destroyed, forming a rubble layer or interface between the surfaces. Further, the formation surfaces can be offset from their original position, forming open apertures between the surfaces. If the volume changes in the proximate formation are repeated, the rubblization may be increased, forming channels through which natural gas, other hydrocarbons, or heated water, may be harvested. The use of an applied mechanical stress may be considered counterintuitive, since such stresses would normally tend to close fractures or cleats, leading to lower production. However, in exemplary embodiments, the application of stress may provide increased permeability and production rates, due to delamination along weak layers and rubblization within the target reservoir, as mentioned above and discussed in further detail below.

[0088] Although shown as be substantially parallel or coplanar with respect to each other in the figures to follow, the zone proximate and the hydrocarbon bearing subterranean formation may be situated in non-parallel planes. The zone proximate and hydrocarbon bearing subterranean formation may also be oriented substantially horizontal, vertical, deviated, folded, originally arched, faulted, or irregularly positioned with respect to the wellbore and each other. Each may comprise a single geologic formation, zone, lens, or structure, or multiple formations, zones, lenses, or structures.

[0089] As discussed herein, embodiments of the present techniques can increase well productivity, lessen environmental impact, enhance well integrity and reliability, and improve well utilization and hydrocarbon recovery by inducing delamination fractures (D-Fracs)

within a hydrocarbon bearing subterranean formation. Further, production rates and the recovery factor may be enhanced by cyclic “rubblization” over the full formation thickness. In contrast to hydraulic fracturing, which is generally halted by geological drainage boundaries, such as faults and pinchouts, delamination fractures may extend beyond geologic
5 drainage boundaries, thereby reducing the number of wells and associated environmental footprint required for economic development. For example, the delamination may cover an area of about nine times the area of the volumetric expansion when the strength of the activated bedding plane interfaces are sufficiently low.

[0090] Fig. 1 is a diagram of a hydraulic fracturing process **100**. The traditional method
10 of fracture stimulation utilizes “hydraulic” pressure pumping and is a proven technology that has been used since the 1940s in more than 1 million wells in the United States to help produce oil and natural gas. In typical oilfield operations, the technology involves pumping a water-sand mixture into subterranean layers where the oil or gas is trapped. The pressure of the water creates tiny fissures or fractures in the rock. After pumping is finished the sand
15 props open the fractures, allowing the oil or gas to escape from the hydrocarbon bearing formation and flow to a wellbore.

[0091] For example, a well **102** may be drilled through an overburden **104** to a hydrocarbon bearing subterranean formation **106**. Although the well **102** may penetrate through the hydrocarbon bearing subterranean formation **106** and into the underburden **108**,
20 perforations **110** in the well **102** can direct fluids to and from the hydrocarbon bearing subterranean formation **106**. The hydraulic fracturing process **100** may utilize an extensive amount of equipment at the well site. This equipment may include fluid storage tanks **112** to hold the fracturing fluid, and blenders **114** to blend the fracturing fluid with other materials, such as proppant **116** and other chemical additives, forming a low pressure slurry. The low
25 pressure slurry **118** may be run through a treater manifold **120**, which may use pumps **122** to adjust flow rates, pressures, and the like, creating a high pressure slurry **124**, which can be pumped down the well **102** to fracture the rocks in the hydrocarbon bearing subterranean formation **106**. A mobile command center **126** may be used to control the fracturing process.

[0092] The goal of hydraulic fracture stimulation is to create a highly-conductive fracture
30 zone **128** by engineering subsurface stress conditions to induce pressure parting of the formation in the hydrocarbon bearing subterranean formation **106**. This is generally performed by injecting fluids with a high permeability proppant **116**, such as sand, into the hydrocarbon bearing subterranean formation **106** to overcome “in-situ” stresses and

hydraulically-fracture the reservoir rock. A number of liquids may be sequentially injected to perform the fracturing. Generally, the liquids will be sequentially increased in viscosity until a highest viscosity fluid is used. Any number of other pumping orders and system may be used in embodiments, for example, when fracturing zones that are proximate to the hydrocarbon bearing subterranean formation.

[0093] The fracture zone **128** may be considered a network or “cloud” of fractures generally radiating out from the well **102**. Depending on the depth of the hydrocarbon bearing subterranean formation **106**, the fractures may often be predominately perpendicular to the bedding planes, e.g., vertical within the subsurface.

[0094] After the fracturing process **100** is completed, the treating fluids are flowed back to minimize formation damage. For example, contact with the fracturing fluids may result in imbibement of the fluids by pores in the hydrocarbon bearing subterranean formation **106**, which may actually lower the productivity of the reservoir. Further, a carefully controlled flowback may ensure proper fracture closure, trapping the proppant **116** in the fractures and holding them open. The fluids may also be flushed to remove the materials, for example, with a solvent, acid, or other material that can dissolve or break down residual traces of the fracturing fluids.

[0095] Stimulation is generally effective at near-well scale, for example, in which the fracture dimensions are in the 100s of feet. Treating and production are often conducted in the same interval, e.g., the portion of the hydrocarbon bearing subterranean formation **106** reached by the well **102**. The fracturing process **100** may use significant amounts of freshwater and proppant materials. The orientation of the fractures is controlled by the local stresses in the hydrocarbon bearing subterranean formation **106** as discussed further with respect to Fig. 2.

[0096] Fig. 2 is a drawing of a local stress state **200** for an element **202** in a hydrocarbon bearing subterranean formation. The state of stress in the earth is defined by the mass of the overburden, the pressure in the pores of the rock, the tectonic stresses governing boundary conditions, and the basic mechanical properties of the rock, such as Young’s modulus or stiffness. The in-situ earth stresses determine the predominant orientation of hydraulic fractures. The presence of natural fractures, the configuration of the completion itself, and the characteristics of the treating fluids may alter the earth stresses near the well and thereby influence growth of hydraulic fractures for a relatively short distance away from the well.

[0097] The earth stresses can be divided into three principal stresses where σ_v is the vertical stress in this drawing, $\sigma_{\max}^H$ is the maximum horizontal stress, and $\sigma_{\min}^h$ is the minimum horizontal stress. These stresses are normally compressive and vary in magnitude throughout the reservoir, particularly in the vertical direction and from layer to layer. The
 5 vertical stress σ_v , is typically the most compressive stress, i.e., $\sigma_v > \sigma_{\max}^H > \sigma_{\min}^h$. However, depending on geologic conditions, the vertical stress could be less compressive than the maximum horizontal stress, $\sigma_{\max}^H$, or than the minimum horizontal stress, $\sigma_{\min}^h$.

[0098] Fractures in a horizontal direction, e.g., perpendicular to a vertically drilled well or parallel to a horizontally drilled well, may be more effective at conducting hydrocarbons
 10 back to the well for production. In deeper wells, the higher vertical stress from the overburden may often force fractures to be predominately vertical, e.g., perpendicular to a horizontally drilled wellbore.

[0099] However, other stress conditions may exist in formations. These stress conditions may contribute to the tendency for horizontal or vertical fractures to form. For example,
 15 depending on geologic conditions, the vertical stress could be substantially equivalent to the orthogonal lateral stresses. In this condition, termed lithostatic, the direction of a fracture may be controlled by any stress perturbations that take place in the formation. One such perturbation is the wellbore itself, which may favor the formation of vertical fractures. Another perturbation would be the creation of a notch in the formation, as discussed with
 20 respect to Fig. 11. The notch may favor the creation of horizontal fractures in the formation.

[0100] In another condition, the formation may be formed from a rock that is orthotropic. In this case, the rock itself is formed along planar layers that favor the formation of fractures along the planes. If the planes are parallel to the surface, the formation will have an increased tendency to form horizontal fractures, even under high vertical stress. As another
 25 example, a formation may be overpressured, in which the formation has a high pore pressure. Under this condition, the high pore pressure may have a tendency to offset a high vertical stress, allowing the fracturing to be controlled by the addition of stress perturbations in the formation. Generally, as the pressure in the hydrocarbon bearing subterranean formation drops, for example, during production, further fracturing may be horizontal due to
 30 reorientation of the stresses. This is discussed in further detail with respect to Fig. 9. The stresses may also be adjusted to favor the growth of horizontal fractures, as discussed with respect to Figs. 9-11.

[0101] Fig. 3 is a drawing of a first mode (mode 1) **300** of fracture formation, commonly resulting from a standard hydraulic fracturing process. Fractures generally propagate in one or more of three primary modes as discussed with respect to Figs. 3 and 7. While, each mode is capable of propagating a fracture, standard hydraulic fracture stimulation predominantly
5 utilizes mode 1 **300**, resulting from “direct” fluid pressure parting of the formation. In mode 1 **300**, the pressure of the hydraulic fracturing fluid either creates fractures or advances pre-existing fractures. The fractures are propagated by tensile breaking of the rock of the formation at the crack tip.

[0102] As noted herein, the fractures may often be nearly vertical and approximately
10 perpendicular to bedding planes. At shallow depths, the fractures produced may be horizontal, in which case they likely will be parallel to bedding planes. In standard hydraulic fracturing, the hydraulic pressure and fluids directly contact the formation being fractured or treated. Application of the traditional hydraulic fracturing method to unconventional hydrocarbon resources, such as tight gas or shale gas reservoirs, requires both large numbers
15 of wells and large numbers of fracture treatments in each well. These requirements are largely driven by the relatively small “effective” area that is created during the hydraulic fracturing process due to inherent limitations in the treating fluids, proppants, reservoir stratigraphy, and in-situ stresses. In embodiments of the present techniques, a new fracturing concept can be used to achieve massive fracture stimulation of wells, particularly for
20 unconventional hydrocarbon resources. In these embodiments, a volumetric increase in a layer adjacent to the hydrocarbon bearing subterranean formation can be used to place a stress on the reservoir, leading to fracturing in the reservoir.

[0103] Fig. 4 is an exemplified drawing of a well treatment system such as a hydraulic fracturing system **400**, wherein a zone **402** below a hydrocarbon bearing subterranean
25 formation **404** is subjected to a volumetric expansion **406**, which can place stress on the hydrocarbon bearing subterranean formation **404** leading to fracturing. The techniques are not limited to a hydrocarbon bearing subterranean formation **404**, but may be used in any number of situations where fracturing a formation layer would be useful, such as in the production of geothermal energy. In the hydraulic fracturing system **400**, all like units are as
30 discussed with respect to Fig. 1. In this embodiment, the drilling and production wastes from the field may be used for the hydraulic fracturing of the zone **402**, lowering the requirements for freshwater over standard hydraulic fracturing. Further, the drilling cuttings may be used to provide a proppant to maintain the fractures open in the zone **402**. The present techniques

are not limited to hydraulic fracturing of the zone **402**. In embodiments, thermal expansion may be used to create the volumetric expansion **406**. Further, a pressurized liquid may be used to cause the volumetric expansion **406** of the zone **402** without fracturing. The volumetric expansion **406** may be cycled by various techniques, such as successive thermal heating and cooling cycles, or successive fluid injections and removal cycles.

[0104] In other embodiments, a volumetric contraction may be used in place of the volumetric expansion **406**. For example, chemical treatment may be applied in the zone **402** to create an area of cavitation around the well **102**, such as by using an acid to remove a portion of the zone **402**. In some embodiments, the volumetric contraction may be provided through production of fluids from non-hydrocarbon productive zone **402** to create subsidence in both the non-hydrocarbon-bearing zone and in the adjacent hydrocarbon bearing subterranean formation **404**. Further, a separate borehole could be drilled in the zone **402** to induce the volumetric contraction. The effects of volumetric contraction may be enhanced by alternately injecting and then producing fluid in successive cycles, for example, over hours, days, weeks, months, or even years.

[0105] In some embodiments, the formation layers of interest are mechanically damaged or “delaminated,” for example, by arching, or bending flexure, of the hydrocarbon bearing subterranean formation **404**. The method used to treat the hydrocarbon bearing subterranean formation **404** would need to create a stress state sufficient to impose delamination fracturing along preferred layers of interest. This may occur from dilating formations in the zone **402** from below, creating an uplift in the hydrocarbon bearing subterranean formation **404**. The delamination fractures may be created without pressurizing the fracture surfaces of the hydrocarbon bearing subterranean formation **404** with treating fluids. As stimulation fluids do not need to contact the surfaces of the formation, the hydrocarbon bearing subterranean formation **404** may not be damaged by imbibement of the treating fluids. The stimulation may be effective at reservoir scale, i.e., the fracture dimensions may be on the order of 1000s of feet. Further, the treating and the production may be conducted in different intervals, using the same or separate wells.

[0106] Fig. 5 is a block diagram of a method **500** for stimulation of a hydrocarbon bearing subterranean formation by treating a formation outside of the reservoir. The method **500** begins at block **502**, with the drilling and completing of a well to the treatment interval. The treatment interval may be a formation under the hydrocarbon bearing subterranean formation, as generally discussed with respect to Fig. 4. In other embodiments, the treatment

interval may be beside or above the hydrocarbon bearing subterranean formation, for example, if the hydrocarbon bearing subterranean formation is in a deviated formation. At block **504**, the treatment interval may be treated, such as by a chemical, thermal, physical, biological, and/or other treatment. For example, fracturing fluids may be injected into the treatment interval. The fracturing fluids may or may not include solids for proppants, such as crushed drilling cuttings from wells. In some embodiments, the treatment may be performed by successively cycling the volume of the treatment interval to cause rubblization of the hydrocarbon bearing subterranean formation. The treatment may be performed by increasing or decreasing underburden support and/or pressure and thereafter providing an expansive or contracting force such as pressure or a heat source into the treatment interval to cause inflation of the treatment interval such as by thermal expansion. Such deflation and inflation may be cyclically performed.

[0107] At block **506**, a production well is completed to the reservoir to produce hydrocarbons. The production well may be drilled after stimulation from the treating well, thereby reducing the potential for subsequent well integrity or reliability issues. In embodiments, the production well may be the same as the treatment well, for example, by creating perforations in the well at the interval of the hydrocarbon bearing subterranean formation, or by drilling production wells from the treatment well. Various well configurations may be used, as discussed further with respect to Figs. 12 and 13. At block **508**, hydrocarbons may be produced from the production well.

[0108] It will be clear that the techniques described herein are not limited to the production of hydrocarbons, but may be used in other circumstances where a subterranean formation is fractured to aid in the production of fluid. For example, in embodiments, the techniques may be used to fracture a hot dry formation layer for use in geothermal energy production. Water or other fluids may then be circulated through the fractures, collected in a production well, and returned to the surface for harvesting heat energy. The wells are not limited to the conformations discussed above. In embodiments, various treating, and producing well patterns and operational schemes may be considered to concurrently optimize reservoir stimulation, gas production, waste disposal, and well operability.

[0109] Fig. 6 is a more detailed schematic view of a delamination fracture stimulation **600** showing the physics that may lead to delamination fracturing. A well **602** may be drilled through a hydrocarbon bearing subterranean formation **604**, and into a treatment interval or zone **606** below the hydrocarbon bearing subterranean formation **604**. The treatment interval

or zone **606** does not have to be adjacent to the hydrocarbon bearing subterranean formation **604**, but may have one or more intervening layers **608**. These layers **608** may lower the chance that a treatment fluid, if used, will leak into the hydrocarbon bearing subterranean formation **604**. Further, if waste tailing are used as proppants, the layers **608** may assist in
5 fixing the tailings in place, lowering the probability that material may migrate into the hydrocarbon bearing subterranean formation **604** or other locations, such as aquifers.

[0110] As the treatment progresses, a volumetric expansion **610** occurs in the treatment interval or zone **606**, which presses upwards on the layers **608**, forming an arch or dome **612** in the hydrocarbon bearing subterranean formation **604**. In the embodiment shown, fluids
10 and/or particulate solids are injected into the treatment interval or zone **606** to dilate, uplift, “arch,” and shear fracture the hydrocarbon bearing subterranean formation **604**. The distance, or vertical distance, between the zone **606** and the hydrocarbon bearing subterranean formation **604** may control the size of the area over which the treatment affects the hydrocarbon bearing subterranean formation **604**. A layer that is further from the
15 hydrocarbon bearing subterranean formation **604** may affect a wider area, but with a lower total movement. For example, if a treatment of a zone **606** located around 50 m under the hydrocarbon bearing subterranean formation **604** caused a vertical motion of about 2 cm over a distance of about 500 m, treatment of a zone **606** located about 100 m under the hydrocarbon bearing subterranean formation **606**, using the same contraction and/or
20 expansion conditions, may cause a vertical motion of about 1 cm over a horizontal distance of about 1000 m.

[0111] Further, the arch or dome **612** may have a highest stress region, e.g., the area in which the fractures form within the hydrocarbon bearing subterranean formation **604**, that is not centered on the injection well **602**. As the distance between the volumetric expansion
25 **610** and the hydrocarbon bearing subterranean formation **604** increases, so does the distance between the well **602** and the highest stress point in the hydrocarbon bearing subterranean formation **604**. Accordingly, if the highest stress point in the hydrocarbon bearing subterranean formation **604** is sufficiently separated from the well **602**, fracturing of the hydrocarbon bearing subterranean formation **604** may be used to couple the fracture field
30 around the highest stress point with the well **602**.

[0112] In addition to separation distance, the choice of the treatment zone **606** may be made on the basis of formation properties, both in the zone **606** and in the hydrocarbon bearing subterranean formation **604**. A relatively impermeable formation may be useful for

treatment using hydraulic fracturing techniques, as the zone **606** may have lower leak-off, making the treatment more efficient. If waste tailings are going to be used, this may be less of an issue, as the zone **606** may be propped open and expanded, even after pressure has leaked off. If thermal expansion is going to be used, the zone **606** may be selected to have a higher coefficient of thermal expansion than other surrounding zones.

[0113] In addition to the properties of the formation within the zone **606**, the properties of the material in the hydrocarbon bearing subterranean formation **604** may also influence the choice of expansion techniques and location. For example, if the hydrocarbon bearing subterranean formation **604** is shale, a slow expansion may not open sufficient cracks, as a ductile shale may have enough plastic deformation to reseal the cracks. Thus, an explosive deformation may cause a fast enough deformation, such as on the order of seconds, to shatter the shale without plastic flow resealing the cracks. In this case, the zone **606** may be selected to have a hard rock, such as granite, that can transfer the energy of expansion to the hydrocarbon bearing subterranean formation **604**.

[0114] A hydrocarbon bearing subterranean formation **604** may often have weaker layers **614**, or even inherent fracture planes **616**. The arching can cause shear stress in the hydrocarbon bearing subterranean formation **604**, leading to sliding or breaking of the hydrocarbon bearing subterranean formation **604** along these layers **614** and fracture planes **616**, as indicated by the arrows **618**, creating delamination fractures **620**. Thus, the delamination fracture stimulation **600** can create a highly-conductive multi-fracture / dual-porosity reservoir system by delaminating formation layers, parting formation within layers, and rubblizing the formation “in-situ.” The injection operations may also create relative movement or displacement between the fracture surfaces along the layers **614** and fracture planes **616** to achieve fracture conductivity, for example, by creating delamination fractures **620** that contain enhanced permeability formation debris. Vertical fractures **622** may also be created during the delamination process. The control of stresses in the formation may be used to control the direction of the fractures, as discussed with respect to Figs. 9 and 10.

[0115] In addition to the injection of fluids, embodiments may induce delamination fractures in the hydrocarbon bearing subterranean formation **604** using in-situ techniques, such as thermal heating, explosive detonations, and the like to enlarge the volume of the treatment interval or zone **606** and thereby increase the stresses at the target formation intervals such that shear-dominated fractures delaminate along, and possibly normal to, the bedding planes.

[0116] The flow conductivity of the delamination fractures may be enhanced by cyclically inflating and deflating the treatment interval or zone **606** such that the delaminated formations “rubblize” due to frictional contact and relative sliding motion between formation surfaces, creating an in-situ propped bed of failed formation material. This is discussed further with respect to Fig. 8.

[0117] In contrast with the direct hydraulic fracture stimulation of a hydrocarbon bearing subterranean formation **604**, the delamination fracture stimulation **600** minimizes direct fluid contact with the formation fracture face, thereby reducing the potential for formation damage and the need for flowback clean-up. Further, fracture “conductivity” is created *in-situ* over the full fracture dimensions, thereby enhancing productivity and eliminating the need for transporting proppants. The fractures **620** may also extend beyond geologic drainage boundaries, such as faults, pinchouts and the like, reducing the number of wells required for economic development. The fracture delamination may be created using “waste disposal” products, such as drill cuttings, produced brines, and the like, to enhance volumetric strain, reducing the need for customized fracturing formulations and large volumes of freshwater. The fracture delamination or other permeability improvement also may be created with non-aqueous techniques to enhance volumetric strain, reducing the need for customized fracturing formulations and large volumes of freshwater.

[0118] In summary, the delamination fracture stimulation **600** is based on three physical components, including delamination, rubblization, and stress control. The relative importance of each of these components is dependent on the parameters of the particular application, for example, the depths of treatment interval or zone **606** and hydrocarbon bearing subterranean formation **604**, the thicknesses of each interval **604** and **606**, the formation properties, the pore pressures, the in-situ stress environments, and the like. These parameters are discussed in more detail with respect to Figs. 7-10.

[0119] Fig. 7 is a drawing **700** of two modes of fracture formation that may participate in delamination fracture stimulation as discussed herein. Both of these modes are based on shearing the rock, rather than tensile parting of the rock. An in-plane shear mode **702** develops a fracture **704** that is aligned (i.e., in the same two-dimensional plane) with the applied shear stress **706**. The in-plane shear mode **702**, also termed mode II, may develop as an arch or bend that distorts a reservoir. Further, the in-plane shear mode **702** may develop horizontal fractures, for example, as some layers **708** are placed under compressive stress, while other layers **710** are released from compressive stress. Additional mode I **300** “non-

hydraulic" tensile fractures also may be incurred from stress arching of the reservoir. Another mode of fracture formation is an anti-plane shear mode **712**, also termed mode III. Similarly, the anti-plane shear mode **712** develops a fracture **714** that also is aligned in the same two-dimensional plane with the applied shear stress **716**. This mode may also

5 participate in both vertical and horizontal fractures as adjacent layers are moved in opposite directions. In embodiments, both mode II **702**, and mode III **712**, or any combinations thereof, may propagate damage and fractures perpendicular or parallel to bedding planes through the use of a volumetric increase in layers outside of a reservoir interval. The shearing modes may cause material to disaggregate.

10 **[0120]** Fig. 8 is a drawing of rubblization **800** during shearing **802** at a fracture boundary **804**. Direct hydraulic fracturing of a reservoir generally causes tensile fracturing of reservoir rocks as discussed with respect mode I shown in Fig. 3. In contrast, the shearing **802** that takes place in embodiments, as discussed with respect to Fig. 7, can force formation surfaces to slide against each other at a bedding plane interface or fracture boundary **804**. Frictional

15 engagement of features on the surfaces may cause the formation to break, leading to the formation of a rubblized layer within or adjacent to the fracture boundary **804**.

[0121] As mentioned previously, the flow conductivity of delamination fractures may be enhanced by cycling the induced flexures such that the delaminated formations "rubblize" within or adjacent to the fracture boundaries **804** due to frictional contact and relative

20 movement between formation surfaces. This process may create a propped bed of failed formation material *in-situ*. Based on measurements of formation debris fields created during movements of faults, the thickness of the rubblized zone adjacent to the delamination fractures may up to about 20 % of the cumulative linear or transverse movement of the fracture surfaces. Although the amount of formation debris created may be lower with each

25 subsequent cycle, significant porosity may be created in fracture debris zones through the cyclic movement. The failed formation is referred to herein as Cyclic Rubblized Material ("CRM"). CRM results in secondary permeability, i.e., dual porosity.

Stress Distribution and Rearrangement

[0122] Fig. 9 is a drawing of an azimuthal rotation **900** of fracture planes **902** within a

30 formation that may occur as a result of cyclic treatment of the formation. The in-situ earth stresses determine the predominant orientation of hydraulic fractures. At shallow depths, hydraulic fractures generally are horizontal and easily create arching, uplift and delamination fractures in formation layers above. However, at deeper depths, hydraulic fractures generally

are vertical and the horizontal stresses must be increased to locally re-orient hydraulic fractures.

[0123] As discussed above with respect to Fig. 2, the earth stresses can be divided into three principal stresses. In this case, σ_v is the vertical overburden stress and is initially the highest stress in the system. Further, $\sigma_{\max}^H$ is the maximum horizontal stress, while $\sigma_{\min}$ is the minimum horizontal stress, where $\sigma_v > \sigma_{\max}^H > \sigma_{\min}^h$. Specially engineered stress conditions may shift the position of the overburden stress to the intermediate ($\sigma_{\max}^H$) or minimum stress ($\sigma_{\min}^h$), especially in regions near the well. For example, the engineering of the stress conditions may be performed by sequentially fracturing and propping the formation, leading to an increase in horizontal stresses. As the horizontal stresses dominate the vertical stresses, the fracture planes will rotate into the horizontal.

[0124] As a result, the axis of each successive fracture plane **902** in a cyclic fracturing process may be slightly shifted or rotated from the last fracture plane **902**, as indicated by an arrow **906**. This may continue until a final fracture plane **908** may be horizontal. Fracture re-orientation is dependent on the characteristics of the pumping treatment (i.e., fluid rheology, temperature, pressure, rate, solids content, treatment duration, shut-down schedule), and generally occurs initially about the “azimuth” axis and subsequently about the “inclination” axis until turning horizontal. The technique shown in Fig. 9 may be used in any embodiment in which stress is changed in the zone proximate to the target formation, including a volume expansion of the zone proximate or a volume decrease in the zone expansion.

[0125] Although the technique discussed with respect to Fig. 9 will increase stress in the formation and rotate the fracture plane to generate horizontal fractures, it will take a number of repetitions to perform the rotation. Other techniques may be used to initiate horizontal fracture in a faster timeframe, as discussed with respect to Figs. 10 and 11.

[0126] Fig. 10 is a drawing **1000** of a vertical well **1002** passing through a reservoir interval **1004** and a treatment interval **1006**, in which a notch **1008** has been formed in the treatment interval. The notch **1008** is a carved indentation in the treatment interval **1006** that creates a stress increase at the tip, promoting a horizontal fracture. The notch **1006** can be created using any number of down hole tools, such as a jet drilling tool. The notch **1006** can also be created using any number of other techniques, such as a short acid wash to create a wormhole in the treatment interval **1006**. The notching is not limited to the treatment interval **1006**, but may also be performed in the reservoir interval **1004** to promote the growth of a horizontal fracture.

[0127] Fig. 11 is a drawing **1100** of the stress distribution in the formation around the tip of a notch **1102**. As can be seen in Fig. 11, the notch **1102** creates a high stress region **1104** at the tip, facilitating an origination of a crack which propagates out in a perpendicular direction **1106** from a well **1108**. This technique may also be used in the hydrocarbon bearing subterranean formation to enhance the growth of horizontal fractures that may be used to couple the well to a fracture field.

Well Configurations

[0128] Figs. 12(A)-(D) are drawings of a number of well configurations that can be used in embodiments of the techniques described herein. Like numbered items are as described with respect to Fig. 4. In Fig. 12 (A), a vertical well **1204** is drilled to penetrate both the hydrocarbon bearing subterranean formation **404** and the zone **402** below the hydrocarbon bearing subterranean formation **404**. A treatment may be performed in the zone **402** to create a stressed region **1206**, which can create a fracture field **1208** in the hydrocarbon bearing subterranean formation **404** by delamination or rubblization. The location of the treatment, e.g., the distance **1210** between the hydrocarbon bearing subterranean formation **404** and the zone **402**, can be selected to achieve the desired results. For example, a closer distance **1210** may increase an uplift in the immediate vicinity of the well **1204**, but may make the total area of the fracture field **1208** smaller. After treatment, the zone **402** may be plugged or isolated, and the well **1204** may be completed in the hydrocarbon bearing subterranean formation **404** and used as a producing well. Depending on the distance **1210** between the zone **402** and the hydrocarbon bearing subterranean formation **404**, fracturing within the bearing subterranean formation **404** may be used to couple the completed well **1204** to a fracture field **1208**.

[0129] In Fig. 12(B), a well **1212** has a horizontal segment **1214** that is drilled through the zone **402** to allow multiple stressed regions **1206**, which can induce a fracture field **1216** over a large area in the hydrocarbon bearing subterranean formation **404**. After treatment, the horizontal segment **1214** of the well **1212** in the zone **402** may be plugged or isolated, and the well **1212** may be completed in the hydrocarbon bearing subterranean formation **404** to be used as a producing well. Depending on the offset **1218** between the well **1212** and the first of the stressed regions **1206**, the well **1212** may coupled to the fracture field **1216** without further fracturing in the hydrocarbon bearing subterranean formation **404**.

[0130] Fig. 12(C) is a drawing of a multilateral well **1220** with a lower horizontal section **1222** in the zone **402** and an upper horizontal section **1224** in the hydrocarbon bearing subterranean formation **404**. The multilateral well **1220** may be used for both stimulation and

production. The treatment may first be performed along the horizontal section **1222** to create multiple stressed regions **1206**. As described herein, the multiple stressed regions **1206** cause the formation of a fracture field **1216** in the hydrocarbon bearing subterranean formation **404**. After treatment, the lower horizontal section **1222** may be isolated and the upper horizontal
5 section **1224** may be completed and used to produce hydrocarbon from the hydrocarbon bearing subterranean formation **404**. Multiple horizontal sections may be drilled through the thickness of the zone **402** to improve treatment results.

[0131] Fig. 12(D) is a drawing of a well **1226** that has a horizontal section **1228**, in the hydrocarbon bearing subterranean formation **404**, and substantially vertical treating arms
10 **1230** extending into the zone **402**. In this embodiment, treatment of the zone **402** is performed in the treating arms **1230**, creating stressed regions **1206**. As described herein, the multiple stressed regions **1206** cause the formation of a fracture field **1216** in the hydrocarbon bearing subterranean formation **404**. After treatment, the treating arms **1230** may be plugged or isolated, and the well **1226** may be completed in the hydrocarbon bearing subterranean
15 formation **404** to produce hydrocarbon as a conventional horizontal well. The design of the well **1226** in Fig. 12(D) allows treatments to be performed both along the azimuth direction of the horizontal section **1228** and in the vertical direction along the treating arms **1230**. This can allow multiple stressed regions **1206** to be formed along each of the treating arms **1230**, as well as selecting the separation between the horizontal section **1228** and the stressed
20 regions **1206**.

[0132] The efficiencies of the well configurations discussed with respect to Fig. 12 may be further improved. For example, the well configurations may be used in branching wells to reach multiple regions of a single hydrocarbon bearing subterranean formation, as discussed with respect to Fig. 13.

25 [0133] Figs. 13(A)-(F) are drawings of a series of branched wells that can use the configurations discussed with respect to Figs. 12(B) and (D). Like numbered items are as discussed with respect to Fig. 12. Figs. 13(A), (B), and (C) illustrate branched arrangements of Fig. 12(B), which may be useful for accessing larger areas in a zone **402**. Fig. 13(A) is a dual lateral well **1302** having two branches in the zone **402**. Fig. 13(B) is a quadri-lateral
30 well **1304** having four branches in the zone **402**. As indicated by Figs. 13(A) and (B), the number of branches may only be limited by such practical considerations as the difficulty of drilling more well branches or the cost of down hole fitting for branched fracturing operations. Further the branches do not need to be linear and parallel. In the embodiment

shown in Fig. 13(C), a pinnate well **1306** has a number of branches in the zone **402** in a tree arrangement.

[0134] Figs. 13(D), (E), and (F) illustrate branched arrangements of Fig. 12(D), which may be useful for accessing larger areas in a zone **402**. Fig. 13(D) is a dual lateral well **1308** having two branches in the hydrocarbon bearing subterranean formation **404**, each branch having multiple treating arms **1230**. Fig. 13(E) is a quadri-lateral well **1310** having four branches in the hydrocarbon bearing subterranean formation **404**, each branch having multiple treating arms **1230**. As indicated by Figs. 13(D) and (E), the number of branches may only be limited by such practical considerations as the difficulty of drilling more well branches or the cost of down hole fitting for branched fracturing operations. Further the branches do not need to be linear and parallel. In the embodiment shown in Fig. 13(F), a pinnate well **1312** has a number of branches in a tree arrangement.

Fracturing Techniques

[0135] Fig. 14 is a drawing **1400** of a technique that may be useful for increasing the effects of the treatment of a zone **402** on the hydrocarbon bearing subterranean formation **404**. Like numbered items are as described with respect to Fig. 4. In the technique, multiple treatment points **1402** are created in the zone **402**. As the injection technique described may take a significant amount of time to effect a change in the zone **402**, the use of multiple treatment points **1402** may amplify the effects, shortening the treatment time. The treatment points **1402** may be fractures, injection locations for poroelastic expansion of the zone **402**, locations of heat sources for thermal expansion of the zone **402**, and the like. Each of the treatment points **1402** may be successively or concurrently inflated by the pumping of high pressure fluid into the treatment points **1402**. The expansion at multiple treatment points **1402** may increase the stress applied to the hydrocarbon bearing subterranean formation **404**, increasing the number or extent of the fractures in a fracture field and shortening the treatment time.

Monitoring the Treatment

[0136] Monitoring and controlling the treatments described herein may be performed by a number of techniques. Stimulation treatments often show their signatures through earth deformation on the surface or within a subterranean formation, which may be captured by appropriate surveillance or monitoring methods. By the measured deformation pattern and magnitude, it is possible to determine whether a desired treatment has been effected. For

example, if an axisymmetric deformation pattern is detected on the surface, one can conclude that treatment is being performed through a horizontal treatment fracture. However, if surface deformation shows two peaks separated by a trough, then treatment is being performed through a vertical fracture. Modeling efforts may be used to establish a direct correlation between surface or subsurface deformation magnitudes and delamination extent in the reservoir for any given geology. The correlation, when implemented in a computer-based system and combined with real-time monitoring technology, may be used to provide on-the-job treatment feedback and results prediction. Potential surveillance options include, among others, tiltmeter arrays installed on the surface or downhole inside dedicated wells, microseismic monitoring, GPS units installed at selected locations on the surface, and InSAR (Interferometric Synthetic Aperture Radar) images of the surface before and after the treatment.

[0137] Tiltmeters are useful devices for monitor the treatment as they can precisely measure the earth deformation induced by the treatment. In addition, they may easily communicate with a computer system so that real-time treatment feedback and optimization may be implemented.

[0138] Microseismic technology may be used to obtain the locations of the shearing events accompanying the treatment, from which approximate shape of the treatment may be obtained. Microseismic technology can also be used for real-time monitoring of the treatment, but it cannot accurately provide the size and shape of the treatment.

[0139] Both GPS units and InSAR images may be used to measure the surface deformation caused by subterranean treatment. Due to the generally low resolution ($>1\text{mm}$) of these techniques, they are applicable only if the treatment volume is extremely large. In addition, real-time monitoring may be difficult to implement as both GPS and InSAR rely on communication with satellites.

[0140] Embodiments of the claimed subject matter may include the methods and systems disclosed in the following lettered paragraphs:

A. A method for fracturing a production formation, including:
drilling a well into a zone proximate to a production formation; and
increasing a volume of the zone through the well in order to apply a mechanical stress to the production formation.

B. The method of paragraph A, including:

isolating a portion of the well that accesses the zone from a portion of the well that accesses the production formation;

completing a portion of the well in the production formation; and

producing hydrocarbons through the well.

5 C. The method of paragraph A, including:

drilling a first horizontal branch from the well into the zone below the production formation;

drilling a second horizontal branch from the well into the production formation;

changing the volume of the zone using the first horizontal branch; and

10 producing hydrocarbons from the production formation using the second horizontal branch.

D. The method of paragraph A, including:

drilling a horizontal branch from the well into the zone; and

changing the volume of the zone at a plurality of points along the horizontal branch.

15 E. The method of paragraph A, including:

drilling a horizontal branch from the well into the production formation;

drilling a plurality of vertical branches into the zone from the horizontal branch; and

changing the volume of the zone at a point along the vertical branch.

F. The method of paragraph A, including:

20 creating a notch in the zone; and

fracturing the zone at the notch to create a horizontal fracture.

G. The method of paragraph A, wherein increasing the volume includes expanding the zone by injecting a pressurized fluid without fracturing the zone.

H. A hydrocarbon production system, including:

25 a hydrocarbon reservoir;

a zone proximate to the hydrocarbon reservoir;

a stimulation well drilled to the zone;

a stimulation system configured to create a volumetric change in the zone through the stimulation well; and

a production well drilled to the hydrocarbon reservoir.

I. The hydrocarbon production system of paragraph H, wherein the stimulation
5 well includes a horizontal segment through the zone and openings at a plurality of locations along the horizontal segment are used to create the volumetric change.

J. The hydrocarbon production system of paragraph H, including a vertical well that is drilled to both the hydrocarbon reservoir and the zone, wherein:

an opening into the zone is used for the volumetric change; and

10 an opening into the hydrocarbon reservoir is used for production.

K. The hydrocarbon production system of paragraph H, wherein:

the stimulation well is a first horizontal branch from a vertical well; and

the production well is a second horizontal branch from a vertical well.

L. The hydrocarbon production system of paragraph H, wherein:

15 the production well includes a horizontal branch through the production formation;
and

the stimulation well includes a plurality of vertical branches off of the horizontal branch that reach into the zone.

M. The hydrocarbon production system of paragraph H, wherein:

20 the stimulation well includes a plurality of horizontal branches in the zone; and

a plurality of openings along each of the plurality of horizontal branches are used to create a volumetric change at each of the plurality of openings.

N. The hydrocarbon production system of paragraph H, wherein:

25 the production well includes a plurality of horizontal branches in the production formation; and

the stimulation well includes a plurality of vertical branches along each of the plurality of horizontal branches, wherein an opening along each of the plurality of vertical branches is used to create a volumetric change at the opening.

O. The hydrocarbon production system of paragraph N, wherein the plurality of horizontal branches are arranged in a dual lateral, quadrilateral, multilateral, or pinnate formation.

[0141] Still other embodiments of the claimed subject matter may include the methods
5 and systems disclosed in the following numbered paragraphs:

1. A method for fracturing a production formation, including:
drilling a well into a zone proximate to a production formation; and
increasing a volume of the zone through the well in order to apply a mechanical stress
to the production formation.
- 10 2. The method of paragraph 1, wherein the mechanical stress is applied to only a
portion of the production formation so as to create a bending motion in the production
formation and cause fractures to form through delamination.
3. The method of paragraph 1, including:
isolating a portion of the well that accesses the zone from a portion of the well that
15 accesses the production formation;
completing a portion of the well in the production formation; and
producing hydrocarbons through the well.
4. The method of paragraph 1, further including:
reversing the volume change; and
20 repeating the volume change for one or more cycles to cause rubblization along a
delamination fracture in the production formation.
5. The method of paragraph 1, including:
drilling a first horizontal branch from the well into the zone below the production
formation;
25 drilling a second horizontal branch from the well into the production formation;
changing the volume of the zone using the first horizontal branch; and
producing hydrocarbons from the production formation using the second horizontal
branch.

6. The method of paragraph 1, including:
drilling a horizontal branch from the well into the zone; and
changing the volume of the zone at a plurality of points along the horizontal branch.
- 5 7. The method of paragraph 1, including:
drilling a horizontal branch from the well into the production formation;
drilling a plurality of vertical branches into the zone from the horizontal branch; and
changing the volume of the zone at a point along the vertical branch.
8. The method of paragraph 1, including:
10 creating a notch in the production formation; and
fracturing the production formation at the notch to create a horizontal fracture.
9. The method of paragraph 1, including:
creating a notch in the zone; and
fracturing the zone at the notch to create a horizontal fracture.
- 15 10. The method of paragraph 1, including monitoring a change in volume of the
zone.
11. The method of paragraph 10, including creating a microseismic map of the
zone.
12. The method of paragraph 10, including tracking changes in angle at a ground
20 surface or in an existing wellbore.
13. The method of paragraph 1, wherein changing the volume includes expanding
the zone by injecting a pressurized fluid without fracturing the zone.
14. The method of paragraph 1, further including producing a hydrocarbon from
the production formation.
- 25 15. A hydrocarbon production system, including:
a hydrocarbon reservoir;
a zone proximate to the hydrocarbon reservoir;
a stimulation well drilled to the zone;

a stimulation system configured to create a volumetric change in the zone through the stimulation well; and

a production well drilled to the hydrocarbon reservoir.

16. The hydrocarbon production system of paragraph 15, wherein the stimulation
5 well includes a horizontal segment through the zone and openings at a plurality of locations along the horizontal segment are used to create the volumetric change.

17. The hydrocarbon production system of paragraph 15, wherein the hydrocarbon reservoir includes a tight gas layer.

18. The hydrocarbon production system of paragraph 15, wherein the hydrocarbon
10 reservoir includes a shale rock, a mudstone rock, a sandstone, or any combinations thereof.

19. The hydrocarbon production system of paragraph 15, including a vertical well that is drilled to both the hydrocarbon reservoir and the zone, wherein:

an opening into the zone is used for the volumetric change; and

an opening into the hydrocarbon reservoir is used for production.

15 20. The hydrocarbon production system of paragraph 15, wherein:
the stimulation well is a first horizontal branch from a vertical well; and
the production well is a second horizontal branch from a vertical well.

21. The hydrocarbon production system of paragraph 20, wherein openings at a plurality of locations along the first horizontal branch are used to create the volumetric
20 change at each opening.

22. The hydrocarbon production system of paragraph 15, wherein:

the production well includes a horizontal branch through the production formation;
and

25 the stimulation well includes a plurality of vertical branches off of the horizontal branch that reach into the zone.

23. The hydrocarbon production system of paragraph 15, wherein:

the stimulation well includes a plurality of horizontal branches in the zone; and

a plurality of openings along each of the plurality of horizontal branches are used to create a volumetric change at each of the plurality of openings.

24. The hydrocarbon production system of paragraph 23, wherein the plurality of horizontal branches are arranged in a dual lateral, quadrilateral, multilateral, or pinnate formation.

25. The hydrocarbon production system of paragraph 15, wherein:
5 the production well includes a plurality of horizontal branches in the production formation; and

the stimulation well includes a plurality of vertical branches along each of the plurality of horizontal branches, wherein an opening along each of the plurality of vertical branches is used to create a volumetric change at the
10 opening.

26. The hydrocarbon production system of paragraph 25, wherein the plurality of horizontal branches are arranged in a dual lateral, quadrilateral, multilateral, or pinnate formation.

27. A method for harvesting hydrocarbons from a formation, including:
15 drilling a production well in a production interval;
drilling a stimulation well in a treatment interval;
causing a volumetric change in the treatment interval through the stimulation well, wherein the volumetric change causes the formation of a fracture field in the production interval;
20 completing the production well to place the production well in contact with the fracture field; and
harvesting hydrocarbons from the production interval.

28. The method of paragraph 27, including:
forming a notch in the rock of the production interval from an opening in the
25 production well; and
fracturing the rock of the production interval through the notch to create a horizontal fracture to the fracture field.

29. The method of paragraph 27, including:
forming a notch in the rock of the treatment interval from an opening in the
30 stimulation well; and

fracturing the rock of the treatment interval through the notch to create a horizontal fracture; and

causing a volumetric increase in the treatment interval by pumping a fluid into the horizontal fracture in the rock of the treatment interval.

- 5 [0142] While the present techniques may be susceptible to various modifications and alternative forms, the embodiments discussed above have been shown only by way of example. However, it should again be understood that the present techniques are not intended to be limited to the particular embodiments disclosed herein. Indeed, the present techniques include all alternatives, modifications, and equivalents falling within the true spirit
10 and scope of the appended claims.

CLAIMS

What is claimed is:

1. A method for fracturing a production formation, comprising:
5 drilling a well into a zone proximate to a production formation; and
increasing a volume of the zone through the well in order to apply a mechanical stress
to the production formation.
2. The method of claim 1, wherein the mechanical stress is applied to only a
10 portion of the production formation so as to create a bending motion in the production
formation and cause fractures to form through delamination.
3. The method of claim 1, comprising:
isolating a portion of the well that accesses the zone from a portion of the well that
15 accesses the production formation;
completing a portion of the well in the production formation; and
producing hydrocarbons through the well.
4. The method of claim 1, further comprising:
20 reversing the volume change; and
repeating the volume change for one or more cycles to cause rubblization along a
delamination fracture in the production formation.
5. The method of claim 1, comprising:
25 drilling a first horizontal branch from the well into the zone below the production
formation;
drilling a second horizontal branch from the well into the production formation;
changing the volume of the zone using the first horizontal branch; and

producing hydrocarbons from the production formation using the second horizontal branch.

6. The method of claim 1, comprising:

5 drilling a horizontal branch from the well into the zone; and
changing the volume of the zone at a plurality of points along the horizontal branch.

7. The method of claim 1, comprising:

drilling a horizontal branch from the well into the production formation;
10 drilling a plurality of vertical branches into the zone from the horizontal branch; and
changing the volume of the zone at a point along the vertical branch.

8. The method of claim 1, comprising:

creating a notch in the production formation; and
15 fracturing the production formation at the notch to create a horizontal fracture.

9. The method of claim 1, comprising:

creating a notch in the zone; and
fracturing the zone at the notch to create a horizontal fracture.

20

10. The method of claim 1, comprising monitoring a change in volume of the zone.

11. The method of claim 10, comprising creating a microseismic map of the zone.

25

12. The method of claim 10, comprising tracking changes in angle at a ground surface or in an existing wellbore.

13. The method of claim 1, wherein changing the volume comprises expanding the zone by injecting a pressurized fluid without fracturing the zone.

14. The method of claim 1, further comprising producing a hydrocarbon from the
5 production formation.

15. A hydrocarbon production system, comprising:
a hydrocarbon reservoir;
a zone proximate to the hydrocarbon reservoir;
10 a stimulation well drilled to the zone;
a stimulation system configured to create a volumetric change in the zone through the stimulation well; and
a production well drilled to the hydrocarbon reservoir.

16. The hydrocarbon production system of claim 15, wherein the stimulation well
15 comprises a horizontal segment through the zone and openings at a plurality of locations along the horizontal segment are used to create the volumetric change.

17. The hydrocarbon production system of claim 15, wherein the hydrocarbon
20 reservoir comprises a tight gas layer.

18. The hydrocarbon production system of claim 15, wherein the hydrocarbon reservoir comprises a shale rock, a mudstone rock, a sandstone, or any combinations thereof.

19. The hydrocarbon production system of claim 15, comprising a vertical well
25 that is drilled to both the hydrocarbon reservoir and the zone, wherein:
an opening into the zone is used for the volumetric change; and
an opening into the hydrocarbon reservoir is used for production.

20. The hydrocarbon production system of claim 15, wherein:
the stimulation well is a first horizontal branch from a vertical well; and
the production well is a second horizontal branch from a vertical well.

5 21. The hydrocarbon production system of claim 20, wherein openings at a plurality of locations along the first horizontal branch are used to create the volumetric change at each opening.

 22. The hydrocarbon production system of claim 15, wherein:
10 the production well comprises a horizontal branch through the production formation;
 and
 the stimulation well comprises a plurality of vertical branches off of the horizontal branch that reach into the zone.

15 23. The hydrocarbon production system of claim 15, wherein:
 the stimulation well comprises a plurality of horizontal branches in the zone; and
 a plurality of openings along each of the plurality of horizontal branches are used to create a volumetric change at each of the plurality of openings.

20 24. The hydrocarbon production system of claim 23, wherein the plurality of horizontal branches are arranged in a dual lateral, quadrilateral, multilateral, or pinnate formation.

 25. The hydrocarbon production system of claim 15, wherein:
25 the production well comprises a plurality of horizontal branches in the production formation; and
 the stimulation well comprises a plurality of vertical branches along each of the plurality of horizontal branches, wherein an opening along each of the

plurality of vertical branches is used to create a volumetric change at the opening.

26. The hydrocarbon production system of claim 25, wherein the plurality of
5 horizontal branches are arranged in a dual lateral, quadrilateral, multilateral, or pinnate formation.

27. A method for harvesting hydrocarbons from a formation, comprising:
drilling a production well in a production interval;
10 drilling a stimulation well in a treatment interval;
causing a volumetric change in the treatment interval through the stimulation well,
wherein the volumetric change causes the formation of a fracture field in the
production interval;
completing the production well to place the production well in contact with the
15 fracture field; and
harvesting hydrocarbons from the production interval.

28. The method of claim 27, comprising:
forming a notch in the rock of the production interval from an opening in the
20 production well; and
fracturing the rock of the production interval through the notch to create a horizontal
fracture to the fracture field.

29. The method of claim 27, comprising:
25 forming a notch in the rock of the treatment interval from an opening in the
stimulation well; and
fracturing the rock of the treatment interval through the notch to create a horizontal
fracture; and

causing a volumetric increase in the treatment interval by pumping a fluid into the horizontal fracture in the rock of the treatment interval.

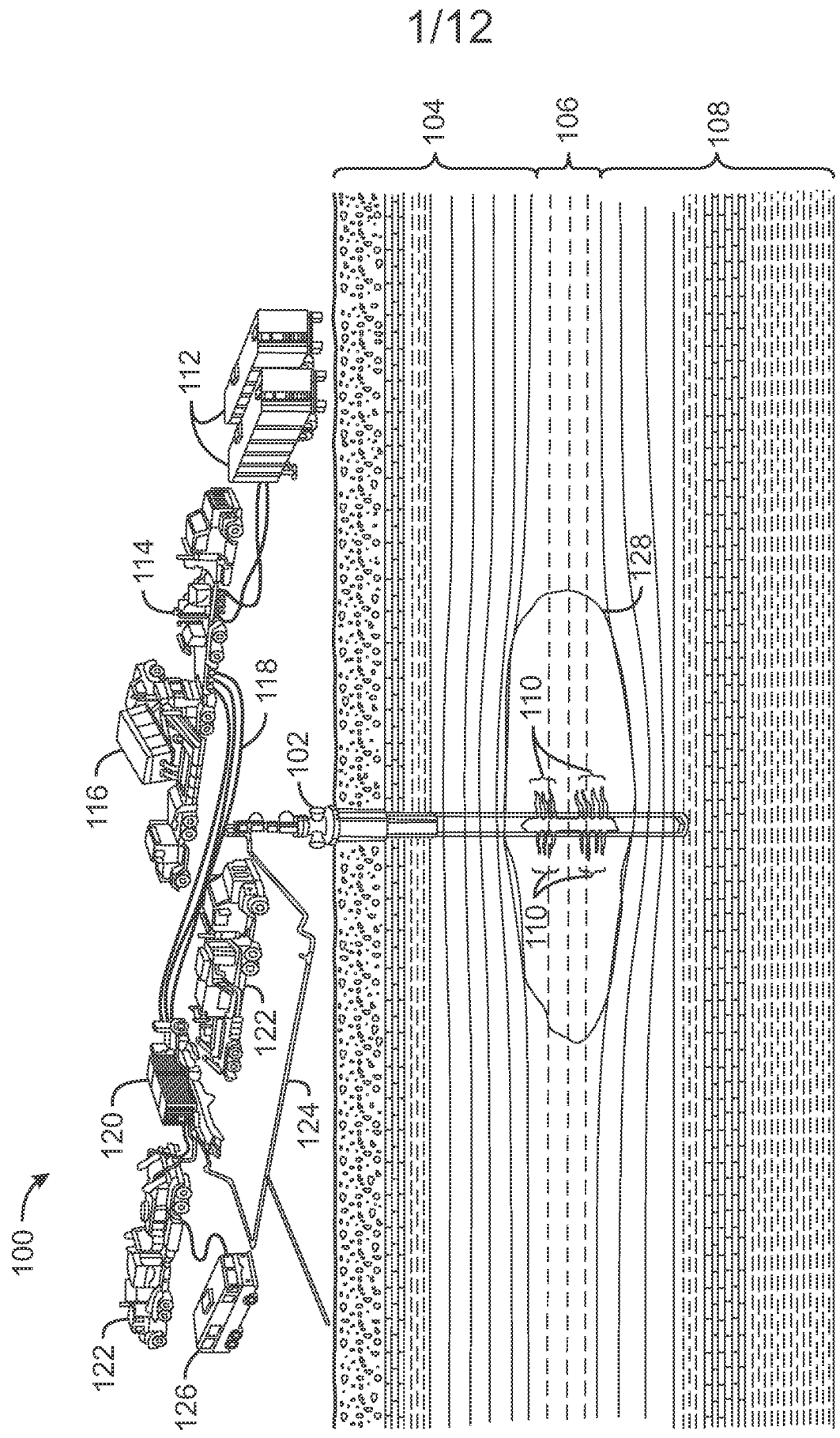
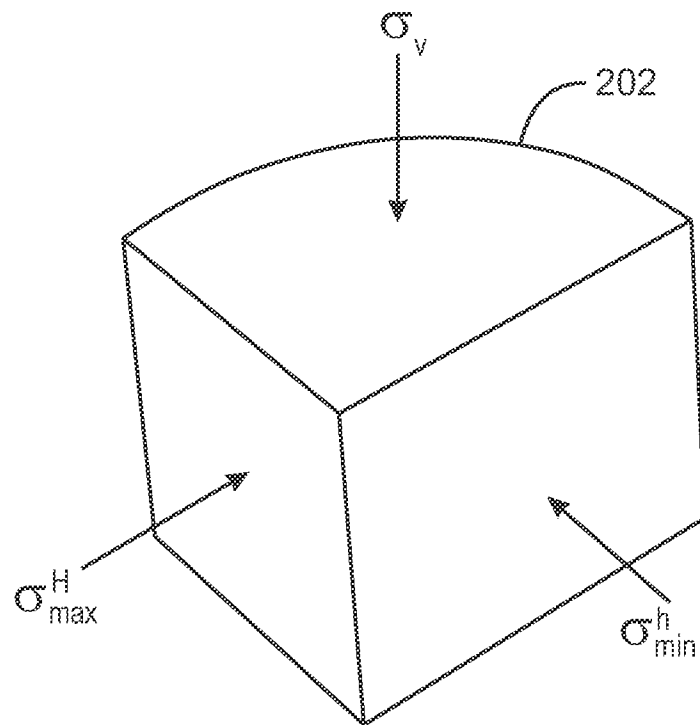


FIG. 1 (PRIOR ART)

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200
FIG. 2

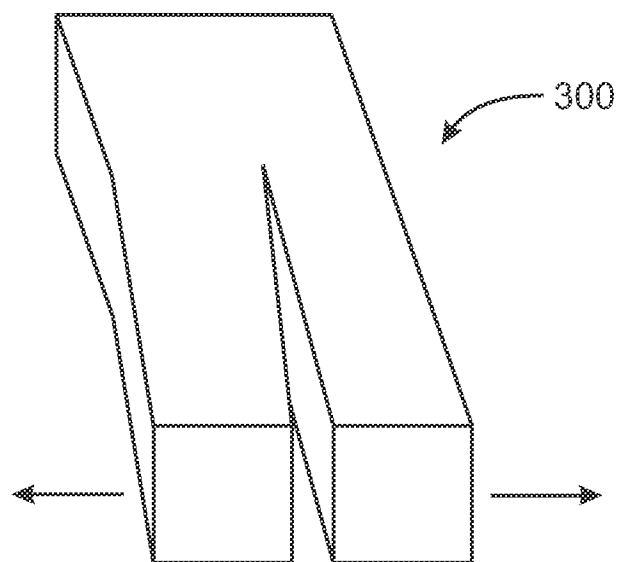
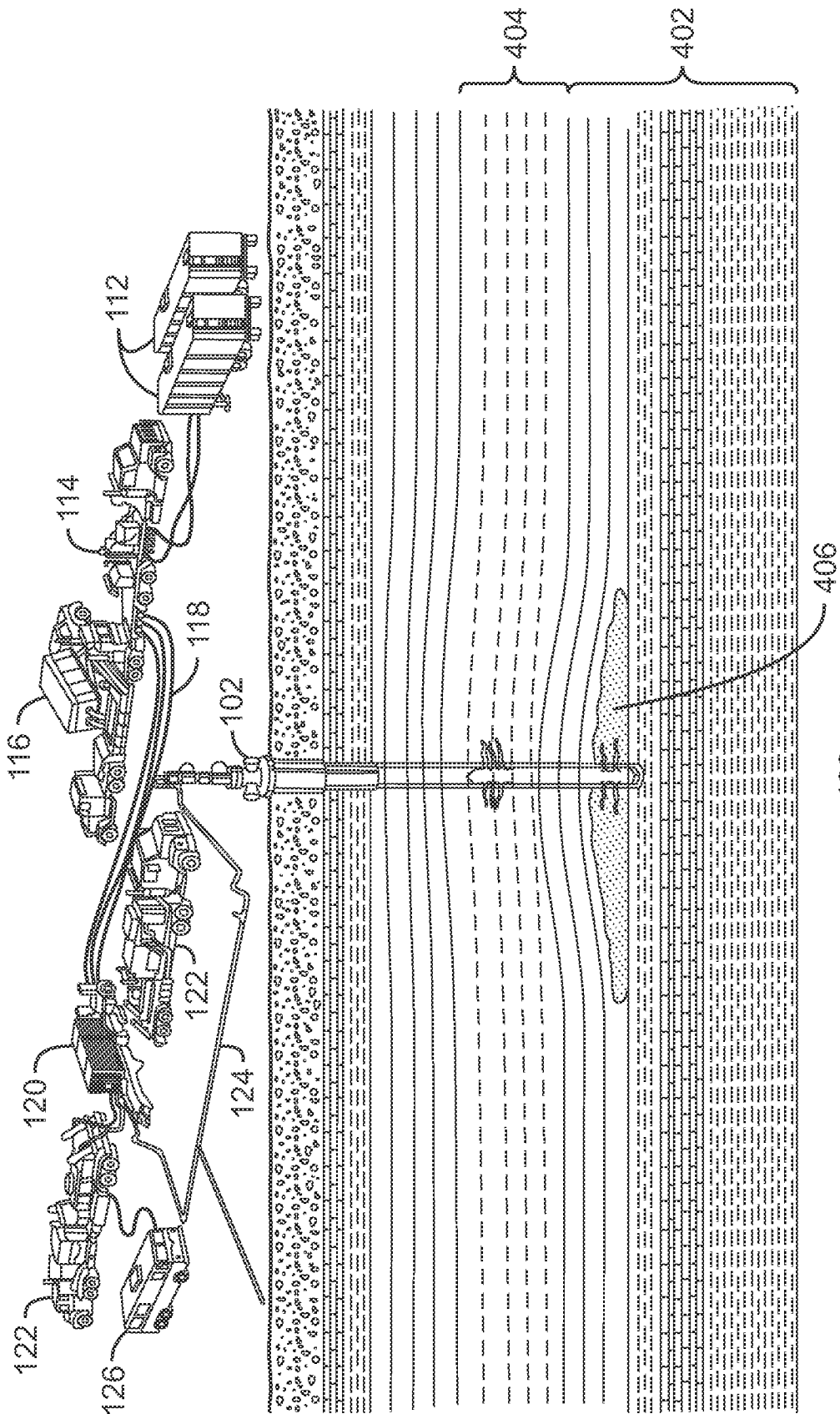
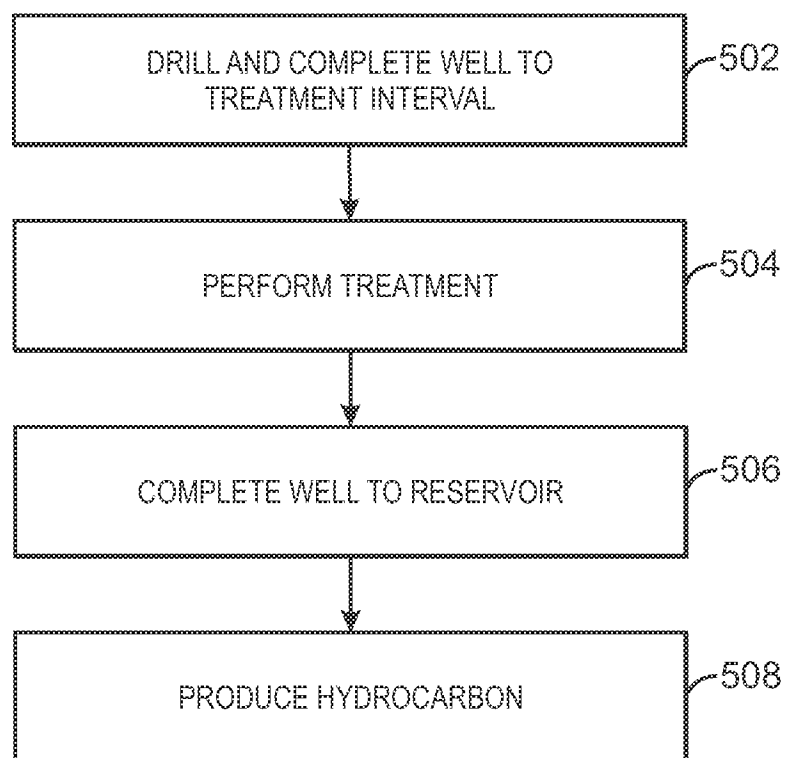


FIG. 3



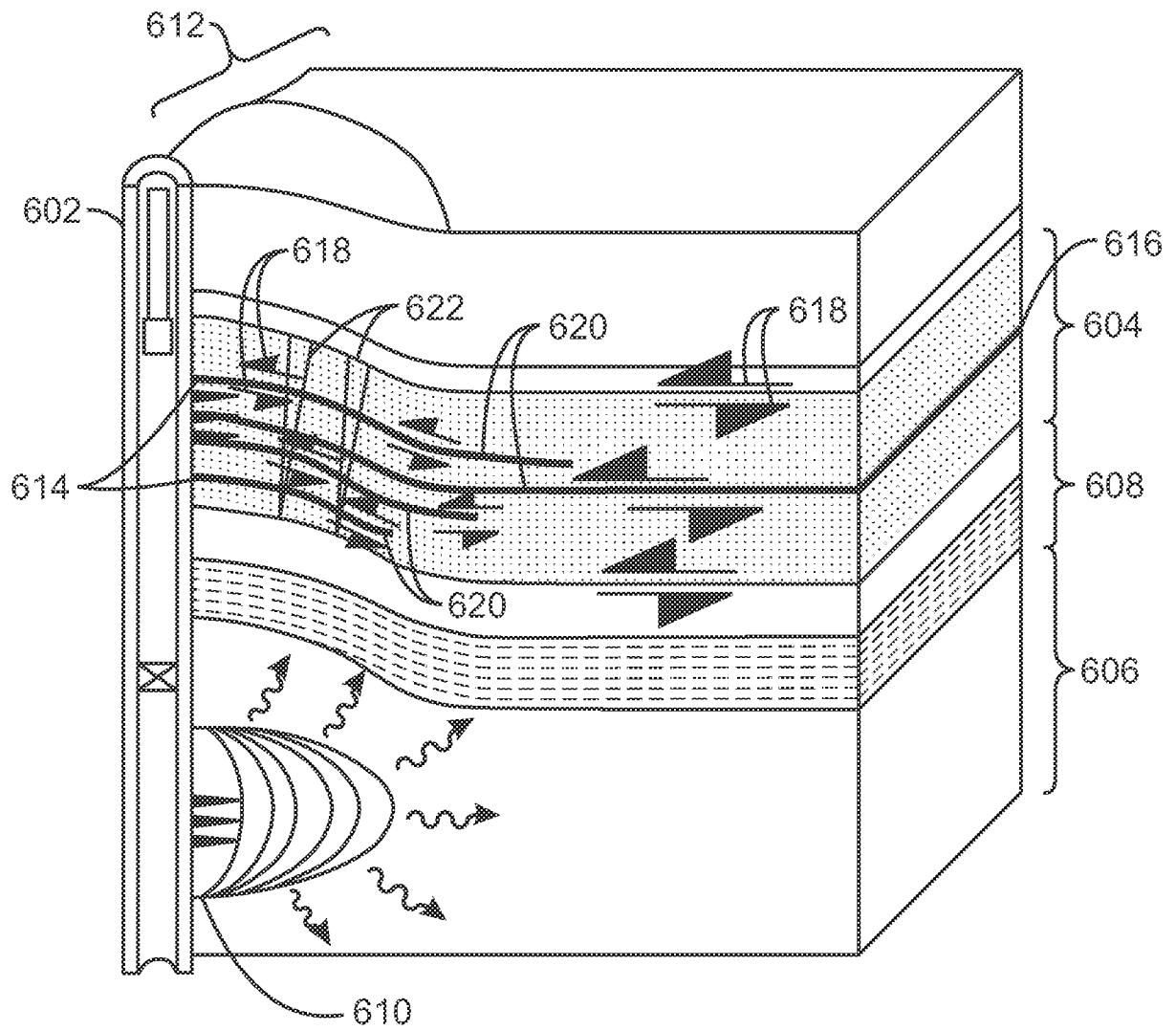
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FIG. 4

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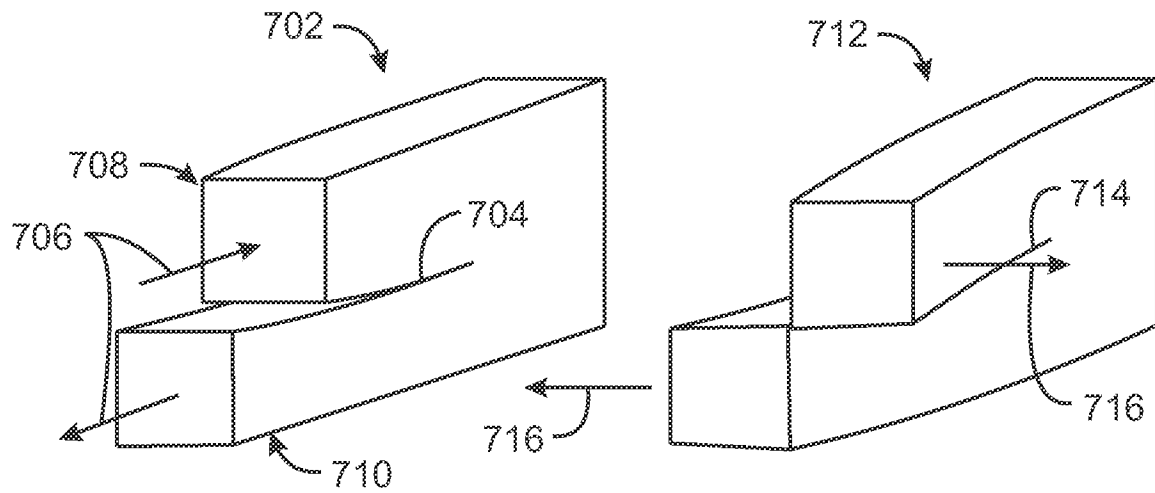
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FIG. 5

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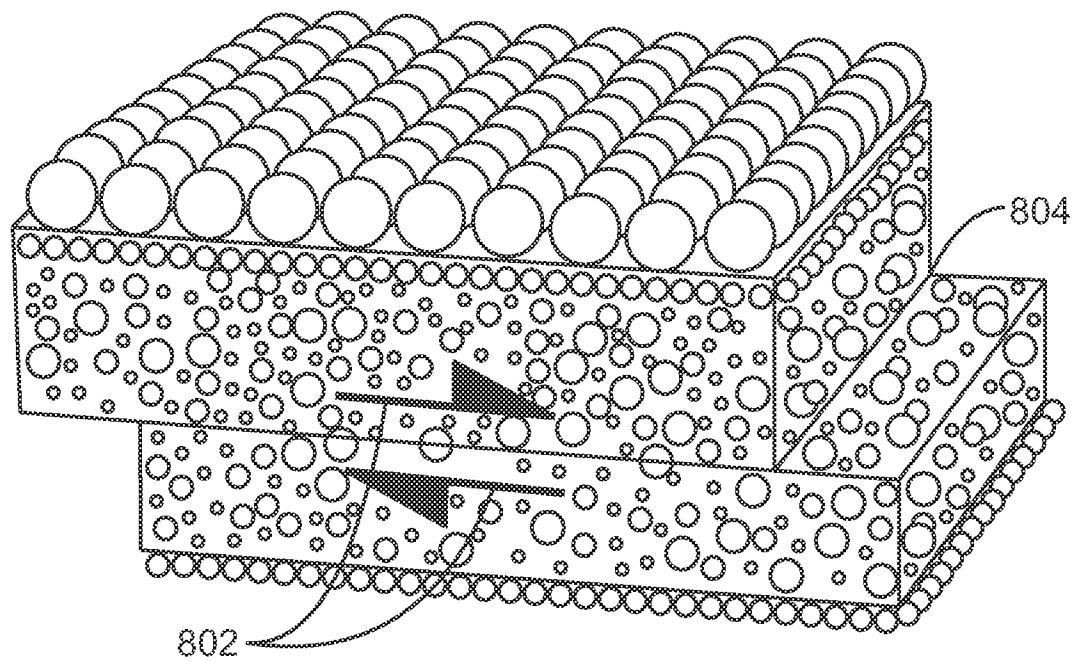


600
FIG. 6

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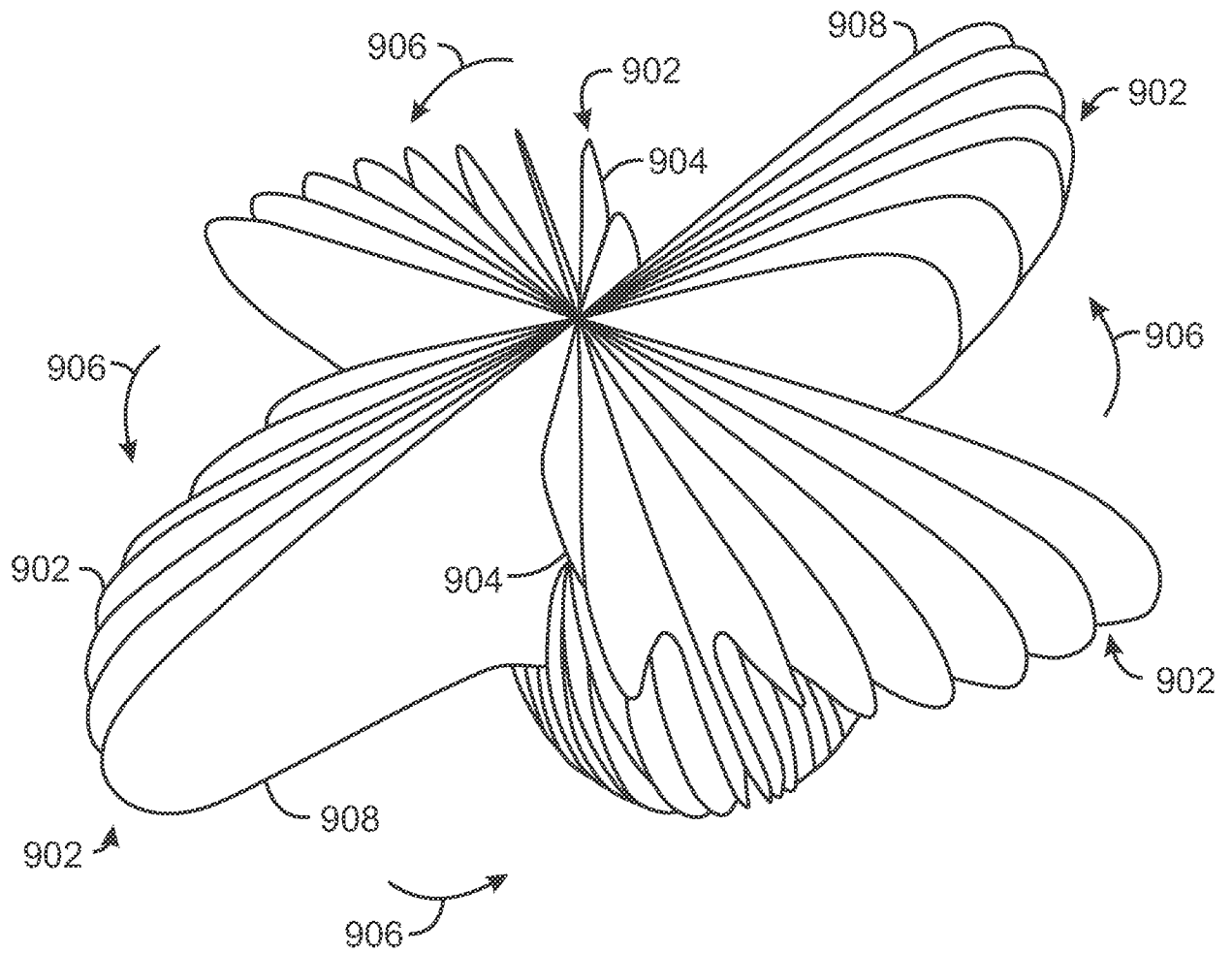


700
FIG. 7



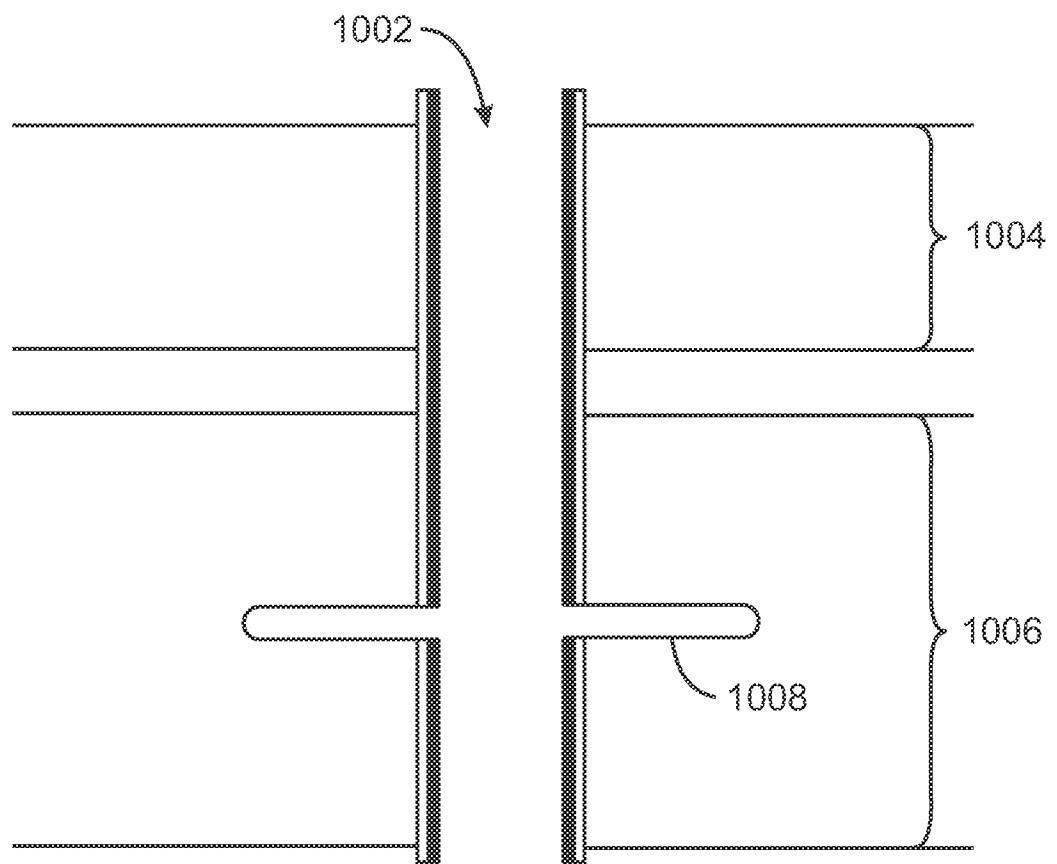
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FIG. 8

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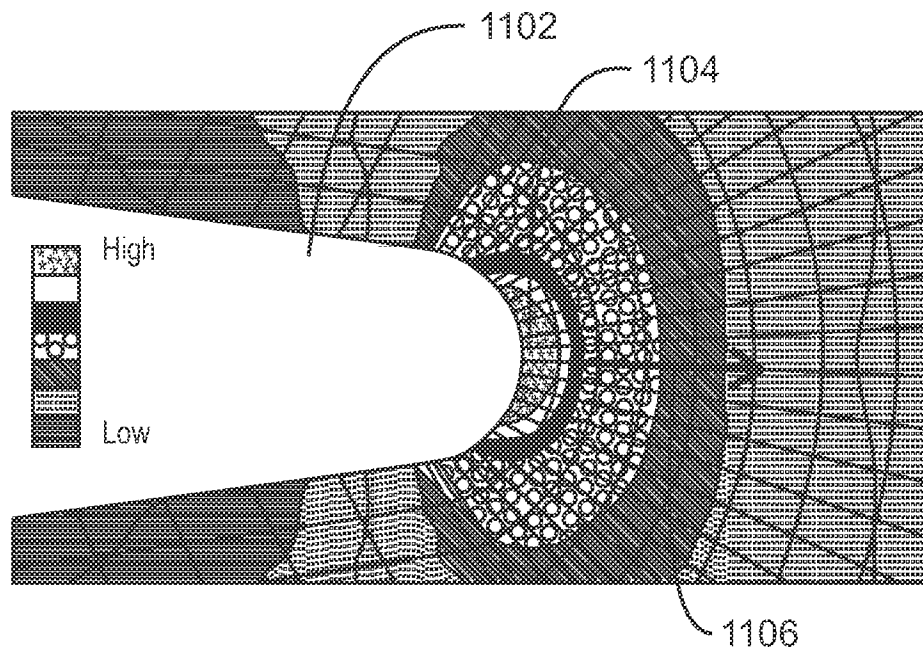
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FIG. 9

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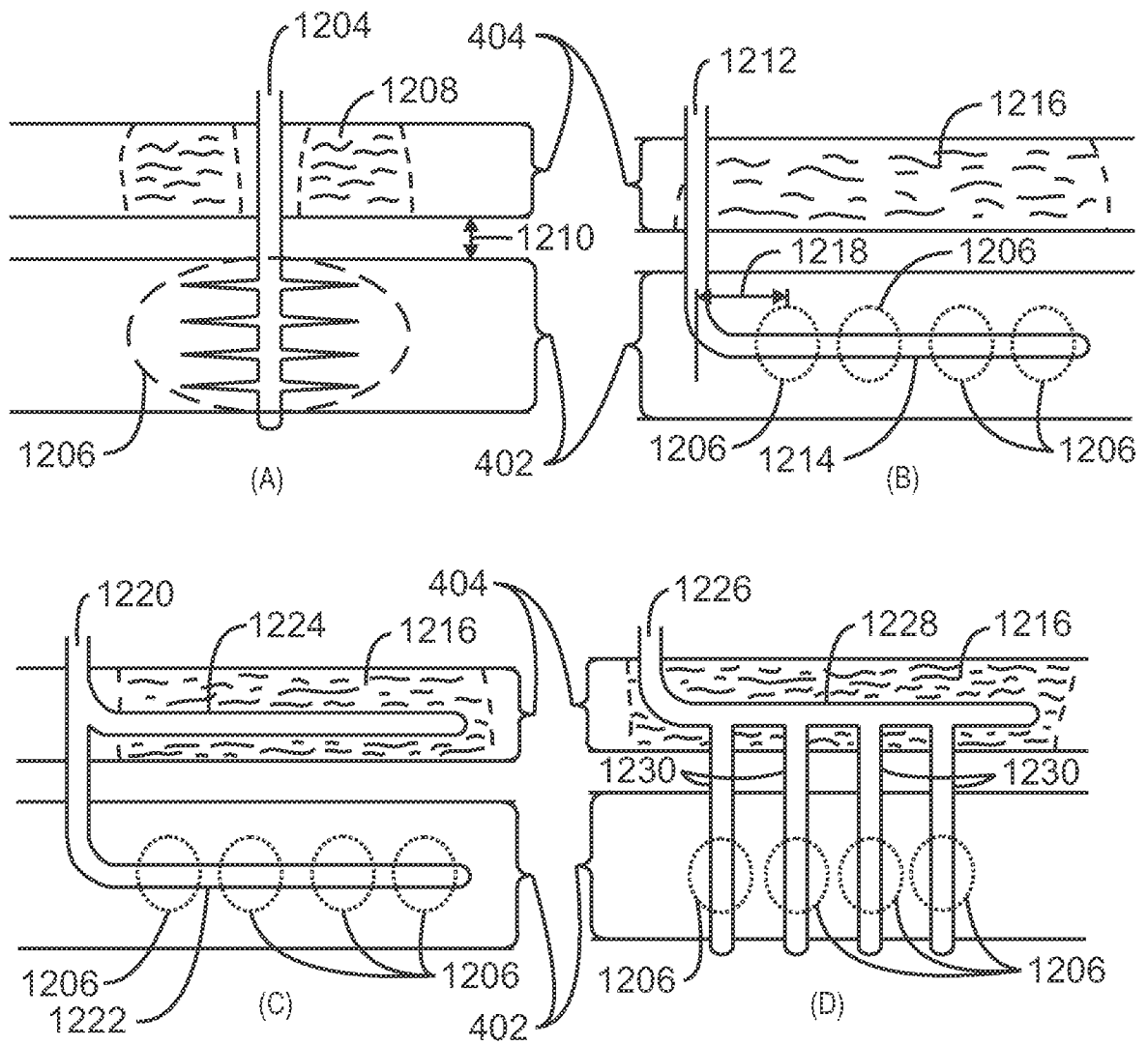
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FIG. 10

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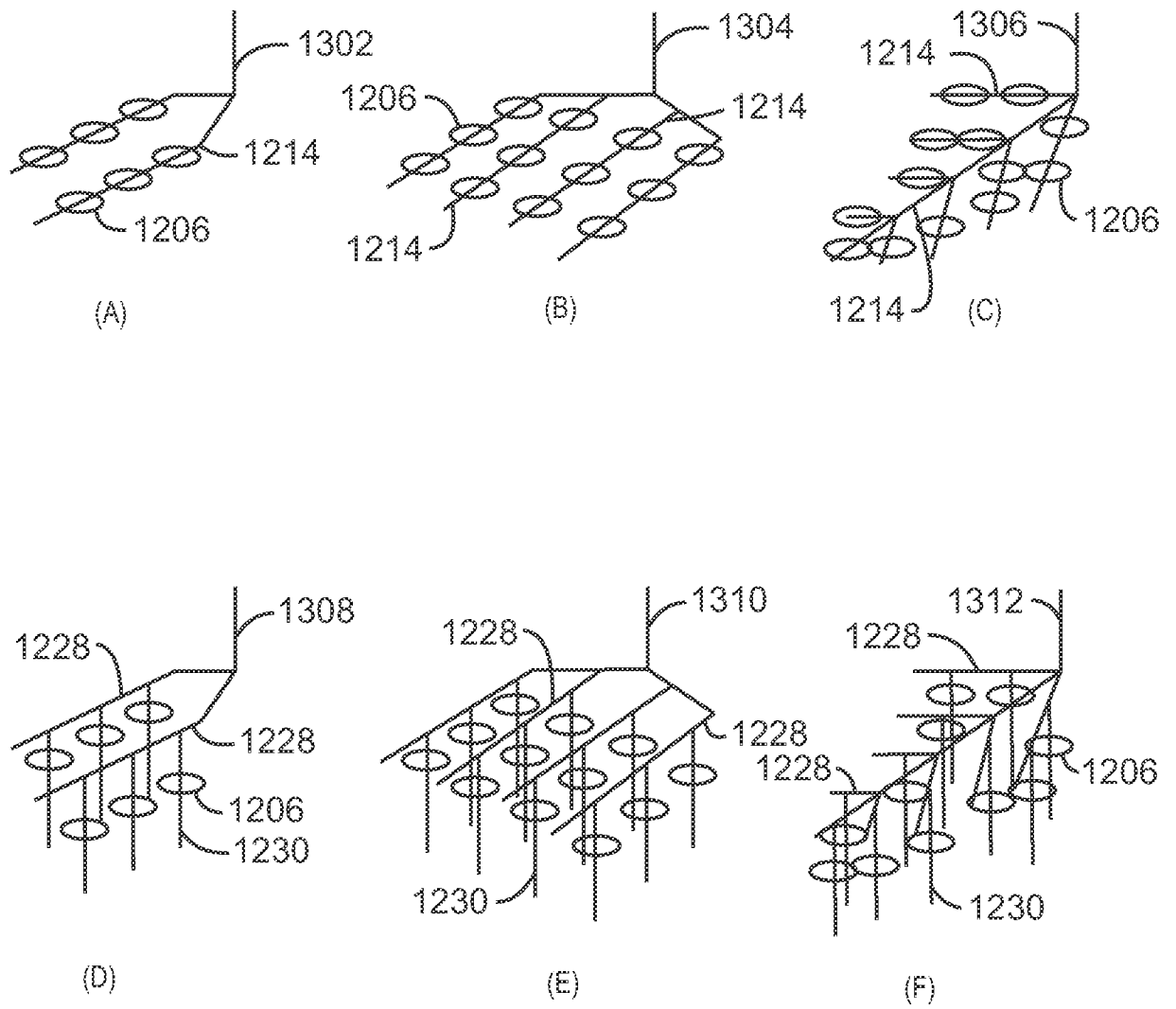
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FIG. 11

10/12



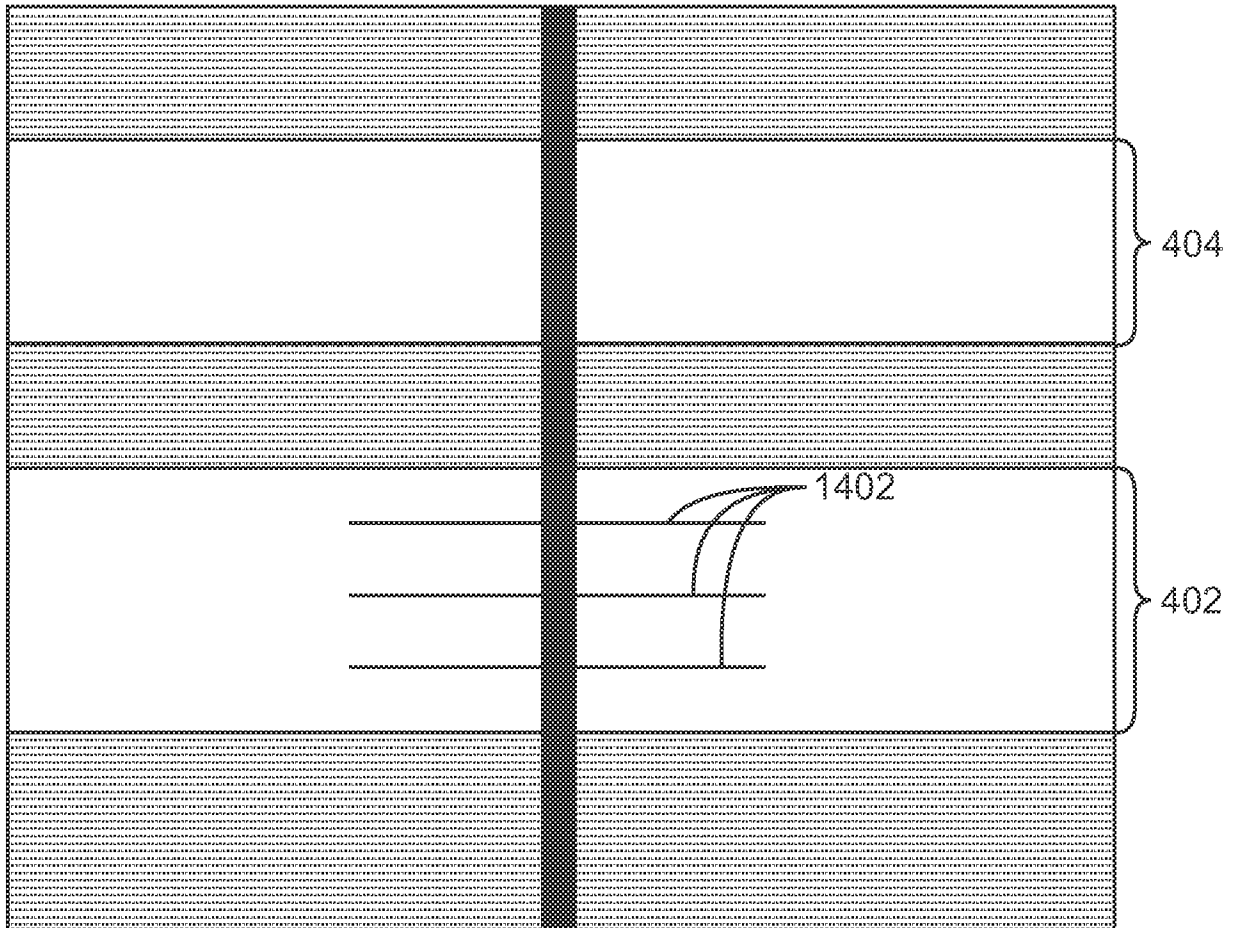
1200
FIG. 12

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1300
FIG. 13

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1400
FIG. 14