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- *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
- *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

[Continued on next page]

(54) Title: METHOD AND SYSTEM FOR FRACTURE STIMULATION BY CYCLIC FORMATION SETTLING AND DIS-
PLACEMENT

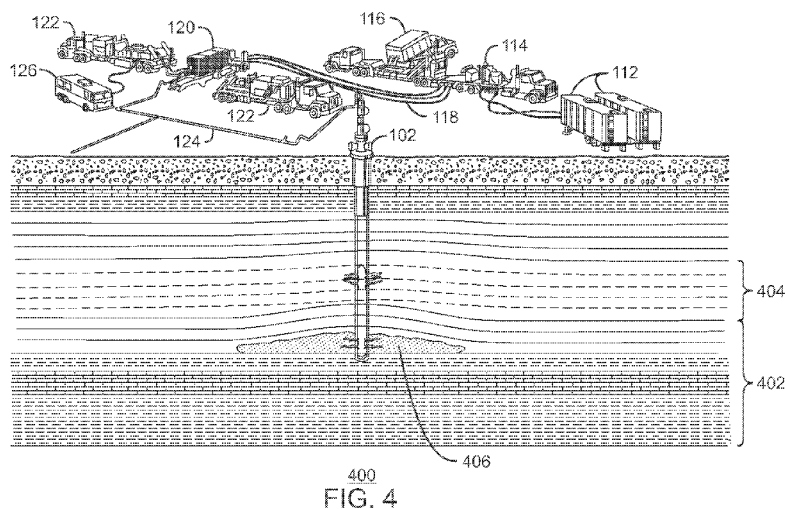


FIG. 4

(57) Abstract: The present techniques provide methods and systems for fracturing reservoirs without directly treating them. For example, an embodiment provides a method for fracturing a subterranean formation. The method includes causing a volumetric decrease in a zone proximate to the subterranean formation so as to apply a mechanical stress to the subterranean formation.



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**METHOD AND SYSTEM FOR FRACTURE STIMULATION BY CYCLIC
FORMATION SETTLING AND DISPLACEMENT**

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 61/407,249, filed October 27, 2010, entitled METHOD AND SYSTEM FOR FRACTURE STIMULATION, and also claims the benefit of 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. This application is also related to concurrently filed International Patent Application, Attorney Docket No. 2010EM298-B, entitled “Method and System for Fracture Stimulation by Formation Displacement”.

FIELD OF THE INVENTION

[0002] Exemplary 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 exemplary 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 rocks 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

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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 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 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 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 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.

[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 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

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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 Abcission Circle in the development of mining horizontal abscission fracture and vertical broken fracture in overlaying rocks; 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

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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; 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, 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 Publications, 169, 51-60 (The Geological Society of London 2000).

SUMMARY

[0014] An embodiment of the present techniques provides a method for fracturing a hydrocarbon-bearing (HC-bearing) subterranean formation, more particularly by directly effecting either increasing stress and strain, or decreasing stress and strain upon or within a formation or portion of a formation that is proximately adjacent to a HC-bearing formation that provides the primary hydrocarbon source for desired HC production. The directly applied stress and strain (whether increased, decreased, or cycled through both effects) is applied in a method that indirectly translates or effects the stress and strain upon the targeted HC-bearing formation, thereby effecting structural or stratigraphic alterations, fractures, rubblization, or other desired effects that increases effective permeability within the HC-bearing formation to enable movement of at least a portion of the previously flow-restricted hydrocarbons toward a wellbore. The method includes causing a bulk volumetric decrease in a zone or formation proximate to the subterranean formation so as to apply or affect a resultant mechanical stress and induced strain or deformation to the proximately adjacent HC-bearing subterranean formation. The methods disclosed herein include at least one step of permitting volume reduction or stress reduction upon the zone proximate so as to enable some degree of settling or other movement within or of the generally adjacent hydrocarbon

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bearing subterranean formation to assist with enhancing the effective permeability to hydrocarbon flow within the subterranean formation.

[0015] In another embodiment, the present techniques may comprise cyclically increasing and decreasing the applied stress to facilitate imparting in the HC-bearing formation, the desired permeability change. Some methods may also create a formation matrix distortion hysteresis in the HC-bearing formation structure that yields improved effective permeability. For simplicity purposes, all such formation changes, subductions, deformations, distortion, cleaving, fracturing, rubblization, microfracturing, or other formation shape or strain changes may be referred to generally as a volumetric “decrease” or volumetric “increase” in bulk formation volume (or volumetric “increase,” as appropriate, such as in a cyclic operation) of both the directly treated formation and the indirectly affected HC-bearing formation, even when an actual volumetric decrease or increase is not actually affected, but is merely facilitated by plastic or elastic formation displacement or compression of the treatment and/or HC-bearing formations and/or compression or displacement of remote compressible or incompressible strata and/or fluid.

[0016] In another embodiment, the new methods presented herein may include A method for fracturing a subterranean formation, comprising: using a wellbore to perform one of the steps of; (a) reducing the geomechanical stress in a zone proximate to the subterranean formation to translate a geomechanical stress change to the subterranean formation to cause a mechanical dislocation of at least a portion of the subterranean formation and create fractures within at least a portion of the subterranean formation; and (b) applying stress in the zone proximate to the subterranean formation to translate a geomechanical stress change to the subterranean formation to cause a mechanical dislocation of at least a portion of the subterranean formation and create fractures within at least a portion of the subterranean formation; and thereafter, using the wellbore to perform the other of step (a) and step (b). In many aspects, step (a) is performed prior to step (b), while in other applications, it may be desirable to perform step (b) prior to step (a).

[0017] In yet another embodiment, the methods included herein may provide for a method for fracturing a subterranean formation, comprising: using a wellbore to perform one of the steps of; (a) reducing the geomechanical stress in a zone proximate to the subterranean formation to translate a geomechanical stress change to the subterranean formation to cause a mechanical dislocation of at least a portion of the subterranean formation and create fractures within at least a portion of the subterranean formation; and (b) applying stress in the zone

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proximate to the subterranean formation to translate a geomechanical stress change to the subterranean formation to cause a mechanical dislocation of at least a portion of the subterranean formation and create fractures within at least a portion of the subterranean formation; and thereafter, using the wellbore to perform the other of step (a) and step (b).

[0018] Another embodiment of the present techniques provides a method for production of a hydrocarbon from a reservoir. The method includes expanding a zone below a hydrocarbon reservoir to mechanically stress the hydrocarbon reservoir and create an arch in the hydrocarbon reservoir. A relative movement may be created across a fracture surface to enhance conductivity.

[0019] In yet another variation for production of a hydrocarbon, the methods may include a method for production of a hydrocarbon from a hydrocarbon bearing formation, comprising: cycling a contraction and expansion of a zone proximate to a hydrocarbon bearing subterranean formation to mechanically stress the hydrocarbon bearing subterranean formation and create an arch in the hydrocarbon bearing subterranean formation; and creating a relative movement across a fracture surface to enhance conductivity.

[0020] A hydrocarbon production system, comprising: a hydrocarbon bearing subterranean formation; a zone proximate to the hydrocarbon bearing subterranean formation; a stimulation well drilled to the zone; and a stimulation system configured to comprise: creating a volumetric decrease; and reversing the volumetric decrease; and repeating the volumetric decrease for one or more cycles.

[0021] Still another embodiment provides a hydrocarbon production system that includes a hydrocarbon reservoir, a zone proximate to the hydrocarbon reservoir, a stimulation well drilled to the zone, and a stimulation system configured to create a volumetric decrease in the zone.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] The advantages of the present techniques are better understood by referring to the following detailed description and the attached drawings, in which:

[0023] Fig. 1 is a diagram of a hydraulic fracturing process;

[0024] Fig. 2 is a drawing of a local stress state for an element in a hydrocarbon bearing subterranean formation;

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[0025] Fig. 3 is a drawing of a first mode of fracture formation, commonly resulting from a standard hydraulic fracturing process;

[0026] Fig. 4 is a schematic of a well treatment process, wherein a zone below a reservoir is subjected to a volumetric decrease, placing stress on an adjacent reservoir layer;

[0027] 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;

[0028] Fig. 6A is a more detailed schematic view of a delamination fracture stimulation;

[0029] Fig. 6B is a more detailed schematic view of another delamination fracture stimulation;

[0030] Fig. 7 is a drawing of two modes of fracture formation that may participate in delamination fracture stimulation as discussed herein;

[0031] Fig. 8 is a drawing of rubblization during shearing at a fracture boundary;

[0032] 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; and

[0033] Fig. 10A is a drawing of a delamination fracturing process illustrating the use of a separate production well and treatment well.

[0034] Fig. 10B is a drawing of another delamination fracturing process illustrating the use of a separate production well and treatment well.

DETAILED DESCRIPTION

[0035] 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 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.

[0036] 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 defined below, it should be given the broadest definition persons in the pertinent art have

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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.

[0037] “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 well.

[0038] “Cleat system” is the system of naturally occurring joints that are created as a coal seam forms over geologic time. The cleat system allows for the production of natural gas if the provided permeability to the coal seam is sufficient.

[0039] “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.

[0040] “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).

[0041] 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.

[0042] “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 subterranean formations or reservoirs by utilizing a plurality of deviated wells that can extend

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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 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.

[0043] “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.

[0044] 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 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.

[0045] “Formation” refers to a body or section of geologic strata, structure, formation, or 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 or a combination of types, or a fraction of strata having substantially common set of characteristics. A formation can contain one or more 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 geologic formation and may generally be a hydrocarbon-bearing zone (a formation, reservoir, or interval having oil, gas, heavy oil, and any combination thereof), and an interval may generally refer to a sub-region or portion of a reservoir. A hydrocarbon-bearing zone may can be separated from other hydrocarbon-bearing zones by zones of lower permeability such as mudstones, shales, or

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shale-like (highly compacted) sands. In one or more embodiments, a hydrocarbon-bearing zone may include heavy oil in addition to sand, clay, or other porous solids.

[0046] A “fracture” is a crack, delamination, surface breakage, separation, crushing, rubblization, or other destruction within a geologic formation or fraction of formation 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 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.

[0047] “Fracturing” refers to the structural degradation of a treatment interval, such as a subsurface shale formation, from applied thermal or mechanical stress. Such structural 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.

[0048] “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 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.

[0049] “Geomechanical stress” (including a change related thereto) or similar phrase, refers generally to the forces external to and/or interior to a formation acting upon or within such formation, which may define a stress state, condition, or property of a formation, zone, or other geologic strata, and/or any fluid contained therein.

[0050] “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 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,

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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 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 open. An electric current may then be passed through the graphite proppant causing it to generate heat, which heats the surrounding formation.

[0051] “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 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 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. 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 mass of the overburden. 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 from the hydrocarbon bearing subterranean formation.

[0052] “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 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

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fracturing the wellbore to promote increased flow, well servicing, well logging, and other well and wellbore treatments.

[0053] “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.

[0054] 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 mass of the overburden.

[0055] “Hydraulic fracturing” is a process used to create fractures that extend from the wellbore into formations to stimulate the potential for production. A fracturing fluid, typically viscous, is generally injected into the formation with sufficient pressure, for example, at a pressure greater than the lithostatic pressure of the formation, to create and extend a fracture. A proppant may often be used to “prop” or hold open the created fracture after the hydraulic pressure used to generate the fracture has been released. Parameters that may be useful for controlling the fracturing process include the pressure of the hydraulic fluid, the viscosity of the hydraulic fluid, the mass flow rate of the hydraulic fluid, the amount of proppant, and the like.

[0056] “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

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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.

[0057] “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 effecting 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.

[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 formation Core Specimens,” ASTM D 2938-95; a “Standard Test Method for Splitting Tensile Strength of Intact formation 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 formation Core Specimens and Determining Dimensional and Shape Tolerances,” ASTM D 4435-01; “Standard Test Method for Elastic Moduli of Intact formation Core Specimens in Uniaxial Compression,” ASTM D 3148-02; “Standard Test Method for Triaxial Compressive Strength of Undrained formation Core Specimens Without Pore Pressure Measurements,” ASTM D 2664-04; “Standard Test Method for Creep of Cylindrical Soft formation Specimens in Uniaxial Compressions,” ASTM D 4405-84, Reapproved 1989; “Standard Test Method for Performing Laboratory Direct Shear Strength Tests of formation Specimens Under Constant Normal Stress,” ASTM D 5607-95; “Method of Test for Direct Shear Strength of formation Core Specimen,” U.S. Military formation Testing Handbook, RTH-203-80, available at “<http://www.wes.army.mil/SL/MTC/handbook/RT/RTH/203->

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80.pdf” (last accessed on June 25, 2010); and “Standard Method of Test for Multistage Triaxial Strength of Undrained formation Core Specimens Without Pore Pressure Measurements,” U.S. Military formation 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 formation specimens 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] “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-containing layer that is relatively impermeable. In some cases, the overburden may be permeable.

[0061] “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 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 (reservoirs).

[0062] “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 =

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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 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).

[0063] “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 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 formation type, Belridge, has very high porosity, at about 60%, but the permeability is very low, for example, less than about 0.1 millidarcy.

[0064] “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).

[0065] As previously mentioned, a “reservoir” or “hydrocarbon reservoir” is defined as a pay zone (for example, hydrocarbon-producing zones) 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.

[0066] “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

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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.

[0067] A “rock physics model” relates petrophysical and production-related properties of a formation 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 formation physics model may provide values that may be used as a velocity model for a seismic survey.

[0068] “Shale” is a fine-grained clastic sedimentary formation with 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 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.

[0069] “Stimulated Rock Volume” (SRV) describes a relatively large formation volume 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 that the formation volume outside of one specific hydraulic fracture experiences improved reservoir properties.

[0070] “Strain” is the fractional change in dimension or volume of the deformation induced in the material by applying stress. For most materials, strain is directly proportional to the stress, and depends upon the flexibility of the material. This relationship between strain and stress is known as Hooke's law, and is presented by the formula: $\epsilon = \frac{\sigma}{E}$

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[0071] “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 .

[0072] “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.

[0073] 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.

[0074] “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 neighboring regions significantly cooler than the heated zone.

[0075] “Tight oil” is used to reference formations with relatively low matrix permeability and/or porosity where liquid hydrocarbon production potential exists. In these formations, liquid hydrocarbon production may also include natural gas condensate.

[0076] “Underburden” refers to the subsurface formation below or farther downhole than the formation containing one or more hydrocarbon-bearing zones (the reservoirs). For example, underburden may include rock, shale, mudstone, or 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 HC-bearing formation or may be a selected fraction within a common formation shared between the underburden portion and the HC-bearing portion. Intermediate layers may also reside between the underburden layer and the HC-bearing zone.

[0077] The “Young's modulus” of a formation or rock sample is the stiffness of the formation sample, defined as the amount of axial load (or stress) sufficient to make the formation sample undergo a unit amount of deformation (or strain) in the direction of load

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application, when deformed within its elastic limit. The higher the Young's modulus, the harder it is to deform. 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.

Overview

[0078] Exemplary embodiments of the present techniques provide techniques for fracture stimulation of reservoirs, or portions of a reservoir, on a large scale, up to stimulating an entire reservoir at once. 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 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 (i.e., low permeability) gas reservoirs.

[0079] The stimulation is generally based on changes to formations other than the target formation itself, for example, by changing a volume of a proximate formation, which places a stress on the target formation. The applied stress can cause delamination of layers and other forms of non-hydraulic fracturing in the target formation, 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 initially in the zone proximate and then translated or otherwise promulgated into the hydrocarbon containing subsurface 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 months, such as if cycling of treatments between reducing the in-situ stress and increasing the stress in the zone proximate are used to open or fracture the subterranean formation rock.

[0080] 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, or the formation surfaces 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; as such stress would normally tend to close fractures or cleats, leading to

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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.

[0081] Fig. 1 is a diagram of a hydraulic fracturing process **100**. The traditional method 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 props open the fractures, allowing the oil or gas to escape from the HC-bearing formation and flow to a wellbore.

[0082] 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**, 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 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.

[0083] The goal of hydraulic fracture stimulation is to create a highly-conductive fracture 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. 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.

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[0084] 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. 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.

[0085] 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.

[0086] The earth stresses can be divided into three principal stresses where σ_z is the vertical stress in this drawing, $\sigma_{\max}$ is the maximum horizontal stress, while $\sigma_{\min}$ is the minimum horizontal stress, where $\sigma_z > \sigma_{\max} > \sigma_{\min}$. However, depending on geologic conditions, the vertical stress could be the intermediate ($\sigma_{\max}$) or minimum stress ($\sigma_{\min}$). These stresses are normally compressive and vary in magnitude throughout the reservoir, particularly in the vertical direction and from layer to layer. The magnitude and direction of the principal stresses are important because they control the pressure required to create and propagate a fracture in the reservoir, the shape of the fracture, the vertical extent of the fracture, the direction of the fracture, and the stresses trying to crush or embed the propping agent during production. 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 back to the well for production. However, in deeper wells, the vertical stresses may often force fractures to be predominately vertical, e.g., perpendicular to a horizontally

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drilled wellbores. As pressure on the hydrocarbon bearing subterranean formation drops, for example, during production, further fracturing may be horizontal. This is discussed in further detail with respect to Fig. 9.

[0087] In other exemplary aspects or description, the earth stresses can be divided into three principal stresses where σ_v is the vertical stress, $\sigma_{\max}^H$ is the maximum horizontal stress (similar to $\sigma_{\max}$ in the paragraph above) and $\sigma_{\min}^h$ is the minimum horizontal stress. Typically, these stresses are normally compressive and vary in magnitude throughout the reservoir, particularly in the vertical direction and from layer to layer. The 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, $\sigma_{\min}^h$.

[0088] 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 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.

[0089] Fig. 3 is a drawing of a first mode (mode I) **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 utilizes mode I **300**, resulting from “direct” fluid pressure parting of the rock. In mode I **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 formation at the crack tip.

[0090] As noted herein, the fractures may often be nearly vertical and approximately 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 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 exemplary embodiments of the present techniques, a new

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fracturing concept can be used to achieve massive fracture stimulation of wells, particularly for unconventional hydrocarbon resources. In these embodiments, a volumetric decrease 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.

[0091] Fig. 4 is an exemplified drawing of a well treatment such as a hydraulic fracturing system 400, wherein a zone 402 below a hydrocarbon bearing subterranean formation 404 is subjected to a volumetric contraction 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 well treatment system 400, all like units are as discussed with respect to Fig. 1. In this exemplary embodiment, a chemical treatment may be applied in the zone 402 to create an area of cavitation. The present techniques are not limited to a chemical treatment of the zone 402. In embodiments, the volumetric contraction 406 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, thereby creating a network of conductive fractures in both zones, including any intermediate zones, such that hydrocarbon can flow from the HC-bearing reservoir to the non-hydrocarbon bearing zone and finally to the wellbore. In some embodiments, the network of conductive fractures may facilitate production of the hydrocarbons directly from the HC-bearing zone directly to the wellbore or another wellbore that is separate from the wellbore used for the treatment process. In other embodiments, a chemical treatment may be applied in the zone 402 to create an area of cavitation. The present techniques are not limited to a chemical treatment of the zone 402. In embodiments, the volumetric contraction 406 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, thereby creating a network of conductive fractures in both zones, including any intermediate zones, such that hydrocarbon can flow from the HC-bearing reservoir to the non-hydrocarbon bearing zone and finally to the wellbore. In some embodiments, the network of conductive fractures may facilitate production of the hydrocarbons directly from the HC-bearing zone directly to the wellbore or another wellbore that is separate from the wellbore used for the treatment process. Further, a borehole could be drilled in the zone 402 to induce the volumetric contraction 406. The volumetric contraction 406 may be enhanced by alternately injecting

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(for example, hours, days, weeks, months, even years) and then producing fluid in successive cycles.

[0092] 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 the stress state to impose delamination fracturing along preferred layers of interest. This may occur from contracting formations in the zone **402** from below. 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.

[0093] 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. For example, a chemical, thermal, physical, biological, and/or other treatment may be injected or introduced into the treatment interval. In embodiments, the treatment may be performed by successively deflating and inflating the treatment interval to cause rubblization of the hydrocarbon bearing subterranean formation. In some embodiments, the treatment may be performed by successively inflating and deflating the treatment interval to cause rubblization of the hydrocarbon bearing subterranean formation. The treatment may be performed by reducing underburden support and/or pressure and thereafter providing an expansive 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.

[0094] 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,

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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. At block **508**, hydrocarbons may be produced from the production well. 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, and well operability.

[0095] Fig. 6A is a more detailed schematic view of a delamination fracture stimulation **600** showing the physics that may lead to delamination fracturing, such as by increasing the volume of (and/or increasing the stresses within) the zone proximate **606**. 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 chemical treatments are used, the layers **608** may assist in fixing the tailings in place, lowering the probability that material may migrate into the hydrocarbon bearing subterranean formation **604** or other locations.

[0096] As the treatment progresses, a volumetric contraction **610** occurs in the treatment interval or zone **606**, which pulls downwards on the layers **608**, forming an arch or dome **612** in the hydrocarbon bearing subterranean formation **604**. In the embodiment shown, fluids are injected into the treatment interval or zone **606** to dilate, subside, “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 hydrocarbon bearing subterranean formation

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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 expansion conditions, may cause a vertical motion of about 1 cm over a horizontal distance of about 1000 m. 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**.

[0097] 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 contraction techniques and location. For example, if the hydrocarbon bearing subterranean formation **604** is shale, a slow contraction may not open sufficient cracks, as a ductile shale may have enough plastic deformation to reseal the cracks.

[0098] 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 rubblelizing the formation “in-situ.” The treatment 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.

[0099] In addition to the injection of fluids, embodiments may induce delamination fractures in the hydrocarbon bearing subterranean formation **604** by producing fluid from zone **606**, to decrease the volume of the treatment interval or zone **606** and thereby increase the stresses at the target formation intervals due to imposed shear stresses such that shear-dominated fractures delaminate along, and possibly normal to, the bedding planes.

[00100] As illustrated in Fig. 6B, the methods disclosed and claimed herein also include at least one step or aspect of permitting a volume reduction and/or stress reduction upon or

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within the zone proximate so as to enable some responsive degree of settling or other movement within or of the generally adjacent hydrocarbon bearing subterranean formation to assist with enhancing the effective permeability to hydrocarbon flow within the subterranean formation. In some embodiments, cyclic operations (e.g., cycling between embodiments such as illustrated in Figs. 6A and 6B, in either order) may be utilized, whereby the subterranean formation is, for example, expanded, displaced, or otherwise stressed to create a fracture network such as via the methods disclosed herein, and then allowed to shrink or move somewhat back to an insitu volume or even beyond insitu to a further settled, distressed, and/or reduced volume (as compared to the original in-situ volume) due to the relief from the applied stress (excepting for hysteresis volume or permeability enhancing effects). In still other embodiments, the volume reduction and/or stress-strain reduction may be prolonged or furthered to effect still additional subsiding, settling, or shrinking in volume or position is affected to cause or effect still further delamination fractures in the hydrocarbon bearing subterranean formation **604**. Volume enhancing techniques may include 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. Volume decreasing techniques may be cyclically followed using techniques such as disclosed within this discussion.

[00101] The flow conductivity of the delamination fractures may be enhanced by cyclically contracting and expanding 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.

[00102] 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 or other permeability improvement may

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be created with non-aqueous techniques to enhance volumetric strain, reducing the need for customized fracturing formulations and large volumes of freshwater.

[00103] 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.

[00104] Fig. 6B is a more detailed schematic view of a delamination fracture stimulation **601** depicting another embodiment of the physics that may lead to delamination fracturing, such as by decreasing the volume of (and/or decreasing the stresses within) the zone proximate **607**. A well **603** may be drilled through a hydrocarbon bearing subterranean formation **605**, and into a treatment interval or zone **607** below the hydrocarbon bearing subterranean formation **605**. The treatment interval or zone proximate **607** does not have to be immediately adjacent to the hydrocarbon bearing subterranean formation **605**, but may be adjacent one or more intervening layers **609**. These layers **609** may lower the chance that a treatment fluid, if used, might (potentially undesirably) leak-off, into the hydrocarbon bearing subterranean formation **605**. Further, if chemical treatments are used, the layers **609** may assist in fixing the tailings in place, lowering the probability that material may migrate into the hydrocarbon bearing subterranean formation **605** or into other undesirable locations.

[00105] As the stress or volume reducing treatment (process) progresses, a volumetric reduction **611** may occur in the treatment interval or zone **607**, which may exert an upward or stress increasing force outward on layers **609**, forming an inverted arch or dome **613** in the hydrocarbon bearing subterranean formation **605**, either near the wellbore or at a reasonable radial distance away from the wellbore. In the embodiment shown, fluids and/or formation material may be removed from the treatment interval or zone **607** to dilate, subside, "arch," fracture, rubblize, and/or shear at least a portion of the hydrocarbon bearing subterranean formation **605**. The distance, or vertical distance, between the zone **607** and the hydrocarbon bearing subterranean formation **605** may control the size of the area over which the treatment affects the hydrocarbon bearing subterranean formation **605**. A layer that is further from the hydrocarbon bearing subterranean formation **605** may affect a wider area, but with a lower total movement. For example, if a treatment of a zone **607** located, say 50 m, under the

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hydrocarbon bearing subterranean formation **605** caused a vertical motion of about 2 cm over a distance of about 500 m, treatment of a zone **607** located about 100 m under the hydrocarbon bearing subterranean formation **607**, using the same contraction and/or expansion conditions, may be assumed for simplified illustration purposes to cause a vertical motion of about 0.5 or 1 cm over a horizontal distance of about 1000 m. In addition to separation distance, the choice of the treatment zone **607** may be made on the basis of formation properties, both in the zone **607** and in the hydrocarbon bearing subterranean formation **605**.

[00106] In addition to the properties of the formation within the zone **607**, the properties of the material in the hydrocarbon bearing subterranean formation **605** may also influence the choice of contraction techniques and location. For example, if the hydrocarbon bearing subterranean formation **605** is shale, a slow contraction may not open sufficient cracks, as a ductile shale may have enough plastic deformation to reseal the cracks.

[00107] A hydrocarbon bearing subterranean formation **605** may often have weaker layers **615**, or even inherent fracture planes **617**. The arching or stress reduction may cause shear stress in the hydrocarbon bearing subterranean formation **605**, leading to sliding or breaking of the hydrocarbon bearing subterranean formation **605** along these layers **615** and fracture planes **617**, as indicated by the arrows **619**, creating delamination fractures **621**. Thus, the delamination fracture stimulation **601** may create a highly-conductive multi-fracture / dual-porosity reservoir system by delaminating formation layers, parting formation within layers, and rubbelizing the formation “in-situ.” The treatment operations may also create relative movement or displacement between the fracture surfaces along the layers **615** and fracture planes **617** to achieve fracture conductivity, for example, by creating delamination fractures **621** that contain enhanced permeability formation debris. Vertical fractures **623** 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.

[00108] In addition to the injection of fluids, embodiments may induce delamination fractures in the hydrocarbon bearing subterranean formation **605** by removing formation volume, fluid, and/or otherwise effecting stress reduction and formation movement from zone **607**, to decrease the volume of the treatment interval or zone **607** and thereby correspondingly decrease or otherwise impact the stresses at the target formation intervals due to imposed shear stresses such that shear-dominated fractures delaminate along, and possibly normal to, the bedding planes.

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[00109] As illustrated in Fig. 6B, the methods disclosed and claimed herein include at least one step or aspect of permitting a volume reduction and/or stress reduction upon or within the zone proximate so as to enable some responsive degree of settling or other movement within or of the generally adjacent hydrocarbon bearing subterranean formation to assist with enhancing the effective permeability to hydrocarbon flow within the subterranean formation. In most embodiments, cyclic operations (e.g., cycling between embodiments such as illustrated in Figs. 6A and 6B, in either order) may be utilized, whereby the subterranean formation is, for example, expanded, displaced, contracted, shrunk, collapsed, subsided, inflated, or otherwise stressed to create a fracture network such as via the methods disclosed herein, and then allowed or caused to reverse the stress change to effect an opposite action, such as to digress somewhat back to an insitu volume (or be caused to displace even beyond the original insitu state) to a settled, de-stressed, and/or reduced volume (as compared to the original in-situ volume) due to the relief from the applied stress (excepting for hysteresis volume or permeability enhancing effects). Cycling may include a single cycle or multiple cycles, and the intervals and/or treatment type for each cycle need not be consistent. In still other embodiments, the volume reduction and/or stress-strain reduction may be prolonged or furthered to effect still additional subsiding, settling, or shrinking in volume or position is affected to cause or effect still further delamination fractures in the hydrocarbon bearing subterranean formation **605**. Volume or stress changing techniques disclosed herein may include using other in-situ techniques, such as thermal heating, explosive detonations, and steam injection, formation dissolution, etc., to enlarge or reduce the volume or overburden supporting capacity of the treatment interval or zone **607** and thereby increase the stresses at the target formation intervals such that shear-dominated fractures delaminate along, and possibly normal to, the bedding planes. Volume decreasing techniques may be cyclically followed using techniques such as disclosed within this discussion.

[00110] The flow conductivity of the delamination fractures may be enhanced by cyclically contracting and expanding the treatment interval or zone **607** such that the delaminated formations “rubblize” along the fracture planes due to frictional contact and relative sliding motion between formation surfaces, creating a naturally propped bed of failed formation material. Such material will also create a fracture or conductivity hysteresis change due to non-reversibility of this type of destruction and displacement. This is discussed further with respect to Fig. 8.

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[00111] In contrast with the conventional direct hydraulic fracture stimulation of a hydrocarbon bearing subterranean formation **605**, the delamination fracture creations **601** may minimize 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 **621** 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 or other permeability improvement may be created with non-aqueous techniques to enhance volumetric strain, reducing the need for customized fracturing formulations and large volumes of freshwater.

[00112] In summary, the delamination and/or fracture-creating treatment **601** 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 **607** and hydrocarbon bearing subterranean formation **605**, the thicknesses of each interval **605** and **607**, 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.

[00113] 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 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

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through the use of a volumetric decrease in layers outside of a reservoir interval. The shearing modes may cause material to disaggregate.

[00114] 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 to 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 fracture boundary **804**. Frictional engagement of features on the surfaces may cause the formation to break, leading to the formation of a rubblized layer within the fracture boundary **804**.

[00115] As mentioned previously, the flow conductivity of delamination fractures may be enhanced by cycling the induced flexures such that the delaminated formations “rubblize” at the fracture boundaries **804** due to frictional contact and relative 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 be 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 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. The cycling of the induced flexures may also relieve stress in the hydrocarbon bearing subterranean formation, which may allow the fracture planes to rotate from vertical to horizontal, as discussed with respect to Fig. 9.

[00116] Fig. 9 is a drawing of an azimuthal rotation **900** of fracture planes **902** within a 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.

[00117] As discussed above with respect to Fig. 2, the earth stresses can be divided into three principal stresses. In this case, σ_z is the vertical overburden stress and is initially the highest stress in the system. Further, $\sigma_{\max}$ is the maximum horizontal stress, while $\sigma_{\min}$ is the minimum horizontal stress, where $\sigma_v > \sigma_{\max} > \sigma_{\min}$. Although, at all depths, injection of fluids

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creates volumetric increases due to pore dilation or formation thermal expansion, the initial fracture plane 904 that forms with the treatment zone may be vertical, which may not place an effective amount of stress on the hydrocarbon bearing subterranean formation. Specially engineered stress conditions may shift the position of the overburden stress to the intermediate ($\sigma_{\max}$) or minimum stress ($\sigma_{\min}$), especially in regions near the well.

[00118] 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.

[00119] Fig. 10A is a simplified illustration of a delamination fracturing process 1000 illustrating the use of a separate production well 1002 and treatment well 1004. The techniques described herein are not limited to using a single well for both treatment and production. In some embodiments, the treatment interval 1006 may be accessed by one or more treatment wells 1004 other than the production well 1002 accessing the reservoir interval 1008. Furthermore, more than one treatment well 1004 may be utilized to achieve a desired degree of volume increasing or stress changing stimulation treatment effect in a production well 1002. Similarly, more than one production well 1002 may be utilized for a single treatment well 1004. Further, various combinations of treatment wells 1004 and production wells 1002 may be located in sufficient proximity to create synergistic enhancement in their interactions.

[00120] Fig. 10B illustrates a simplified delamination fracturing process 1001 indicating the use of a separate production well 1003 and treatment well 1005. The techniques described herein are not limited to using a single well for both treatment and production. In some embodiments, the treatment interval 1007 may be accessed by one or more treatment wells 1005 other than the production well 1003 accessing the reservoir interval 1009. Furthermore, more than one treatment well 1005 may be utilized to achieve a desired degree of volume reducing or stress changing stimulation effect in a production well 1003. Similarly, more than one production well 1003 may be utilized for a single treatment well 1005. Further, various combinations of treatment wells 1005 and production wells 1003 may be located in sufficient proximity to create synergistic enhancement in their interactions.

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[00121] To recap, in one embodiment, the inventive methods include a method for fracturing a subterranean formation, comprising changing the stress and strain in a zone proximate to the subterranean formation to indirectly translate a mechanical stress or strain change to the subterranean formation and effect a permeability increase within the subterranean formation, and thereafter reversing that geomechanical stress change in the zone proximate to at least partially reverse the fracturing or formation displacement in the subterranean formation and thereby increase the fracturing, rubblization, and/or delamination in the subterranean formation. The change may be created by first reducing the stress level in the zone proximate from an insitu state, and thereafter increased to produce strain and permeability changes in the subterranean formation; or the change may be created by first increasing the stress level in the zone proximate from the insitu state and thereafter decrease the same to produce strain and permeability changes in the subterranean formation.

[00122] A single wellbore may be used to reach both the zone proximate and the hydrocarbon bearing subterranean formation, or separate wellbore 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 vertical wells, horizontal wells, multi-branch wells, deviated wellbores, and combinations thereof. Similarly, the zone proximate and hydrocarbon bearing subterranean formation may be substantially parallel or coplanar with respect to each other, or situated in non-parallel planes, and each may comprise a single geologic formation, zone, lens, or structure, or multiple formations, zones, lenses, or structures. 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.

[00123] In many embodiments, the desired permeability increase is effected by creation of a fracture network in the subterranean formation, such as by delamination fracturing during uplifting, down-folding or other affected movement of the subterranean formation. The desired permeability may also be the result of other types of fracturing, but is noted that for simplification purposes, all such fracturing and displacements may be referred to herein generally as fracturing.

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[00124] The volumetric increase in the zone proximate is created 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 or rubblization network is created within the subterranean formation.

[00125] In some embodiments, stress may be introduced into the zone proximate in the form of, or so as to effect a reduction in, a reduction of structural support within the zone proximate that is then translated into at least a partially corresponding reduction in stability in the hydrocarbon bearing subterranean formation, resulting in creation of a fracture or rubblization network 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 underreamed 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. 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.

[00126] As discussed in the above paragraphs, applying stress changes to the zone proximate may cause the zone proximate to either arch (expand, bow, collapse, settle, or otherwise displace or experience growth or reduction in volume, with the effect of such action generally being most prominent in the vicinity of the wellbore or point of application or introduction, and then radiating or diffusing outwardly from the point of such application or introduction) toward or away from the subterranean formation, whereby the subterranean formation may arch compliantly as a result of such actions in the zone proximate and as translated through any intermediate formations. Stated differently, the applied stress in the zone proximate produces a stress reduction or increase in the in-situ or pre action stress level in the zone proximate, producing strain in the zone proximate, and enables at least a portion

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(the affected portion) of the subterranean formation to arch toward or away from, as appropriate, at least a portion of the zone proximate, producing a fracture (including rubblization) network in at least a portion of the arched or affected portion of the subterranean formation.

[00127] In another embodiment, the methods of the present techniques may include a method for fracturing a subterranean formation, comprising: using a wellbore to perform one of the steps of; (a) reducing the geomechanical stress in a zone proximate to the subterranean formation to translate a geomechanical stress change to the subterranean formation to cause a mechanical dislocation of at least a portion of the subterranean formation and create fractures within at least a portion of the subterranean formation; and (b) applying stress in the zone proximate to the subterranean formation to translate a geomechanical stress change to the subterranean formation to cause a mechanical dislocation of at least a portion of the subterranean formation and create fractures within at least a portion of the subterranean formation; and thereafter, performing the other of step (a) and step (b). In many embodiments, the wellbore is also used to perform the other of step (a) and step (b).

[00128] It is noted that the techniques and methods disclosed herein are described generally from two different standpoints, although both are closely related. In one standpoint, the techniques are described in terms of creating or effecting “volumetric changes” (increase or decrease, or both) in the zone proximate and/or in the subterranean formation. As discussed herein, many of the methods used to accomplish the objectives and techniques disclosed herein (e.g., to fracture, rubblize, delaminate a geologic formation objective to create improved permeability within a hydrocarbon or other reservoir or formation), may effect a volumetric change in such formations or zones, relative to an insitu or pre-treatment state. From another standpoint, the methods herein are described in terms of altering the geomechanical stresses of a formation (including external and/or internal stresses), such alterations including volumetric changes, but also including dislocation, displacement, strain changes, and/or fracturing of a zone proximate or subterranean formation, without substantial volumetric change therein, but which otherwise none-the-less effect translation of force, stress, and/or energy (either applied or reduced, as compared to pretreatment levels) from a zone proximate to an objective subterranean formation. The common steps include, generally, treating a zone proximate to effect a stress change therein or thereupon, to effect permeability increases in a hydrocarbon bearing subterranean

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formation. Both such descriptions are within the scope of the present inventive methods and techniques.

[00129] As discussed herein, embodiments of the present techniques can increase well productivity, lessen environmental impact, enhance well integrity & reliability, and improve well utilization and hydrocarbon recovery. 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 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 contraction.

[00130] Still other embodiments of the claimed subject matter may include:

1. A method (500) for fracturing a subterranean formation (404, 604), comprising causing (504) a volumetric decrease (406, 610) in a zone (402, 606) proximate to the subterranean formation (404, 604) so as to apply a mechanical stress to the subterranean formation (404, 604).

2. The method of paragraph 1, wherein the zone (402, 606) is below the subterranean formation (404, 604).

3. The method of paragraph 1, wherein the mechanical stress is applied to only a portion of the zone (402, 604) so as to create a bending motion in the subterranean formation (404, 604) and cause fractures (614, 620, 622) to form through delamination (618).

4. The method of paragraph 1, further comprising:
reversing the volumetric decrease (406, 610); and
repeating the volumetric decrease (406, 610) for one or more cycles to cause rubblization (800) along a delaminated joint (804).

5. The method of paragraph 1, wherein the subterranean formation (404, 604) comprises a hydrocarbon formation.

6. The method of paragraph 1, wherein creating the volumetric decrease (406, 610) comprises pumping a fluid into the zone to create a chemical reaction (402, 604).

7. The method of paragraph 1, wherein creating the volumetric decrease (406, 610) comprises producing fluid from the zone (402, 604).

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8. The method of paragraph 1, wherein creating the volumetric decrease (406, 610) comprises creating a cavitation within the zone (402, 604).

9. A hydrocarbon production system (400), comprising:
a hydrocarbon bearing subterranean formation (404);
a zone (402) proximate to the hydrocarbon bearing subterranean formation (404);
a stimulation well (102) drilled to the zone (402); and
a stimulation system configured to create a volumetric decrease (406) in the zone (402).

10. The hydrocarbon production system of paragraph 9, wherein the hydrocarbon bearing subterranean formation (404) comprises an unconventional gas layer.

11. The hydrocarbon production system of paragraph 9, wherein the zone (402) comprises a formation layer in an underburden.

12. The hydrocarbon production system of paragraph 9, comprising a production well drilled into the hydrocarbon bearing subterranean formation (404).

13. The hydrocarbon production system of paragraph 9, comprising a production well drilled into the hydrocarbon bearing subterranean formation (404) from the stimulation well (102).

[00131] Still other embodiments may include the methods disclosed in the following paragraphs:

1. A method for fracturing a subterranean formation, comprising:
using a wellbore to perform one of the steps of;
(a) reducing the geomechanical stress in a zone proximate to the subterranean formation to translate a geomechanical stress change to the subterranean formation to cause a mechanical dislocation of at least a portion of the subterranean formation and create fractures within at least a portion of the subterranean formation; and
(b) applying stress in the zone proximate to the subterranean formation to translate a geomechanical stress change to the subterranean formation to cause a mechanical dislocation of at least a portion of the subterranean formation and create fractures within at least a portion of the subterranean formation; and
thereafter, performing the other of step (a) and step (b).

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2. The method of paragraph 1, wherein step (a) is performed prior to step (b).
3. The method of paragraph 1, wherein step (b) is performed prior to step (a).
4. The method of paragraph 1, wherein the geomechanical stress of the zone proximate in step (a) is reduced from an initial in-situ geomechanical stress state in the zone proximate to a geomechanical stress state in the zone proximate that is less than the original in-situ geomechanical stress of the zone proximate, prior to performing step (b).
5. The method of paragraph 1, wherein the geomechanical stress of the zone proximate in step (a) is reduced from the applied geomechanical stress in the zone proximate after first performing step (b).
6. The method of paragraph 5, wherein the geomechanical stress of the zone proximate in step (a) is reduced to a geomechanical stress state that is less than the in-situ geomechanical stress of the zone proximate prior to performing step (a).
7. The method of paragraph 1, wherein the geomechanical stress of the zone proximate in step (b) is increased from an initial in-situ geomechanical stress state in the zone proximate to a geomechanical stress state in the zone proximate that is greater than the original in-situ geomechanical stress of the zone proximate prior to performing step (a).
8. The method of paragraph 1, wherein the geomechanical stress of the zone proximate in step (b) is increased from the reduced geomechanical stress in the zone proximate after first performing step (a).
9. The method of paragraph 8, wherein the geomechanical stress of the zone proximate in step (b) is increased to a geomechanical stress state that is greater than the in-situ geomechanical stress of the zone proximate prior to performing step (a).
10. The method of paragraph 1, wherein the geomechanical stress of the zone proximate in step (b) is increased from the reduced geomechanical stress in the zone proximate after first performing step (a), to a geomechanical stress level in the zone proximate that is greater than the geomechanical stress level in the zone proximate prior to previously performing step (a) in the zone proximate.
11. The method of paragraph 1, wherein the geomechanical stress of the zone proximate in step (a) is decreased from the increased geomechanical stress in the zone proximate after first performing step (b), to a geomechanical stress level in the zone

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proximate that is less than the geomechanical stress level in the zone proximate prior to previously performing step (a) in the zone proximate.

12. A method for fracturing a subterranean formation, comprising:

using a wellbore to perform one of the steps of;

(a) reducing the geomechanical stress in a zone proximate to the subterranean formation to translate a geomechanical stress change to the subterranean formation to cause a mechanical dislocation of at least a portion of the subterranean formation and create fractures within at least a portion of the subterranean formation; and

(b) applying stress in the zone proximate to the subterranean formation to translate a geomechanical stress change to the subterranean formation to cause a mechanical dislocation of at least a portion of the subterranean formation and create fractures within at least a portion of the subterranean formation; and

thereafter, using the wellbore to perform the other of step (a) and step (b).

13. The method of paragraph 1, wherein step (a) is performed prior to step (b).

14. The method of paragraph 1, wherein step (b) is performed prior to step (a).

15. The method of paragraph 12, wherein the subterranean formation comprises a hydrocarbon formation.

16. The method of paragraph 12, wherein the zone proximate comprises a formation layer in an underburden.

17. The method of paragraph 12, wherein step (a) creates a volumetric decrease in bulk volume of the zone proximate and the volumetric decrease is caused by a decrease in pore pressure within the zone proximate.

18. The method of paragraph 12, wherein step (b) creates a volumetric increase in bulk volume of the zone proximate and the volumetric increase is caused by an increase in pore pressure within the zone proximate.

19. The method of paragraph 17, wherein the decrease in pore pressure results in subsidence of the subterranean formation.

20. The method of paragraph 12, wherein step (a) creates a volumetric decrease in the zone proximate and the volumetric decrease is effected by a method that comprises

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pumping a fluid into the zone proximate to create a chemical reaction that reduces bulk volume of the zone proximate.

21. The method of paragraph 20, wherein the chemical reaction comprises chemicals which dissolve regions of the zone.

22. The method of paragraph 20, wherein the chemical reaction comprises and endothermic reaction that contracts the zone.

23. The method of paragraph 12, wherein step (a) creates a volumetric decrease in the zone proximate and the volumetric decrease is effected producing fluid from the zone proximate.

24. The method of paragraph 12, wherein creating the volumetric decrease comprises material excavation from the zone proximate.

25. The method of paragraph 24, wherein the excavation within the zone proximate comprises at least one of introduction of abrasive fluids into the zone proximate, creating a wellbore tunnel within the zone proximate, collapsing a wellbore within the zone proximate, creating perforation tunnels within the zone proximate, leaching a soluble material from the zone proximate, dissolving soluble material from the zone proximate, gasification of material from the zone proximate, and eroding formation material from the zone proximate.

26. The method of paragraph 12, further comprising producing a hydrocarbon from the subterranean formation.

27. The method of paragraph 12, further comprising producing a geothermally heated fluid from the subterranean formation.

28. A method for production of a hydrocarbon from a hydrocarbon bearing formation, comprising:

cycling a contraction and expansion of a zone proximate to a hydrocarbon bearing subterranean formation to mechanically stress the hydrocarbon bearing subterranean formation and create an arch in the hydrocarbon bearing subterranean formation; and

creating a relative movement across a fracture surface to enhance conductivity;

29. The method of paragraph 28, wherein the hydrocarbon bearing subterranean formation comprises a tight gas reservoir.

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30. The method of paragraph 28, wherein the hydrocarbon bearing subterranean formation comprises a shale gas reservoir.

31. The method of paragraph 28, wherein the hydrocarbon bearing subterranean formation comprises a coal bed methane reservoir.

32. The method of paragraph 28, wherein the hydrocarbon bearing subterranean formation comprises a tight oil reservoir.

33. The method of paragraph 28, further comprising cycling the contraction of the zone proximate by reducing the in-situ stress in the zone proximate so as to cause at least a portion of the subterranean formation to arch in a direction toward the zone proximate.

34. The method of paragraph 28, further comprising cycling the expansion of the zone proximate by applying stress to the zone proximate so as to cause at least a portion of the subterranean formation to arch in a direction away from the zone proximate.

35. The method of paragraph 28, wherein the relative movement across a fracture surface creates a stimulated formation volume

36. The method of paragraph 34, further comprising producing a hydrocarbon from the hydrocarbon bearing subterranean formation.

37. The method of paragraph 34, comprising drilling a production well from the stimulation well into the hydrocarbon bearing subterranean formation.

38. The method of paragraph 28, further comprising drilling a production well into the hydrocarbon bearing subterranean formation after the treatment is completed.

39. The method of paragraph 28, further comprising drilling a production well into the hydrocarbon bearing subterranean formation before the treatment is completed.

40. The method of paragraph 28, further comprising where the cycling cause the zone to rubblize a layer of material along a delamination joint with the hydrocarbon bearing subterranean formation.

41. A hydrocarbon production system, comprising:

a hydrocarbon bearing subterranean formation;

a zone proximate to the hydrocarbon bearing subterranean formation;

a stimulation well drilled to the zone; and

a stimulation system configured to comprise:

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creating a volumetric decrease; and
reversing the volumetric decrease; and
repeating the volumetric decrease for one or more cycles.

42. The hydrocarbon production system of paragraph 41, wherein the hydrocarbon bearing subterranean formation comprises a tight gas layer.

43. The hydrocarbon production system of paragraph 41, wherein the hydrocarbon bearing subterranean formation comprises a shale gas layer.

44. The hydrocarbon production system of paragraph 41, wherein the hydrocarbon bearing subterranean formation comprises a coal bed methane layer.

45. The hydrocarbon production system of paragraph 41, wherein the hydrocarbon bearing subterranean formation comprises a tight oil layer.

46. The hydrocarbon production system of paragraph 41, wherein the zone comprises a formation layer in an underburden.

47. The hydrocarbon production system of paragraph 41, comprising a production well drilled into the hydrocarbon bearing subterranean formation.

48. The hydrocarbon production system of paragraph 41, comprising a production well drilled into the hydrocarbon bearing subterranean formation from the stimulation well.

49. A method for fracturing a subterranean formation, comprising:

causing a volumetric decrease in a zone proximate the subterranean formation so as to apply a geomechanical stress change to the subterranean formation, wherein the geomechanical stress change creates an arch-like bending movement in at least a portion of the subterranean formation and causes fractures to form in the subterranean formation;

reversing the volumetric decrease in the zone proximate to cause a volumetric increase in the zone proximate so as to at least partially reverse the geomechanical stress change in the subterranean formation; and

thereafter repeating the volumetric decrease in the zone proximate to cause further fracturing in the subterranean formation.

50. The method of paragraph 49, wherein the caused fracture and caused further caused fractures within the subterranean formation are caused through delamination of rock layers within the subterranean formation during arching of the subterranean formation.

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51. The method of paragraph 49, further comprising changing stress in the zone proximate to cause at least a portion of the subterranean formation to arch in a direction away from the zone proximate.

52. The method of paragraph 49, further comprising changing stress in the zone proximate to cause at least a portion of the subterranean formation to arch in a direction toward the zone proximate.

[00132] While the present techniques may be susceptible to various modifications and alternative forms, the exemplary 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 and scope of the appended claims.

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CLAIMS

What is claimed is:

1. A method for fracturing a subterranean formation, comprising:
using a wellbore to perform one of the steps of;
 - (a) reducing the geomechanical stress in a zone proximate to the subterranean formation to translate a geomechanical stress change to the subterranean formation to cause a mechanical dislocation of at least a portion of the subterranean formation and create fractures within at least a portion of the subterranean formation; and
 - (b) applying stress in the zone proximate to the subterranean formation to translate a geomechanical stress change to the subterranean formation to cause a mechanical dislocation of at least a portion of the subterranean formation and create fractures within at least a portion of the subterranean formation; andthereafter, performing the other of step (a) and step (b).
2. The method of claim 1, wherein step (a) is performed prior to step (b).
3. The method of claim 1, wherein step (b) is performed prior to step (a).
4. The method of claim 1, wherein the geomechanical stress of the zone proximate in step (a) is reduced from an initial in-situ geomechanical stress state in the zone proximate to a geomechanical stress state in the zone proximate that is less than the original in-situ geomechanical stress of the zone proximate, prior to performing step (b).
5. The method of claim 1, wherein the geomechanical stress of the zone proximate in step (a) is reduced from the applied geomechanical stress in the zone proximate after first performing step (b).
6. The method of claim 5, wherein the geomechanical stress of the zone proximate in step (a) is reduced to a geomechanical stress state that is less than the in-situ geomechanical stress of the zone proximate prior to performing step (a).

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7. The method of claim 1, wherein the geomechanical stress of the zone proximate in step (b) is increased from an initial in-situ geomechanical stress state in the zone proximate to a geomechanical stress state in the zone proximate that is greater than the original in-situ geomechanical stress of the zone proximate prior to performing step (a).

8. The method of claim 1, wherein the geomechanical stress of the zone proximate in step (b) is increased from the reduced geomechanical stress in the zone proximate after first performing step (a).

9. The method of claim 8, wherein the geomechanical stress of the zone proximate in step (b) is increased to a geomechanical stress state that is greater than the in-situ geomechanical stress of the zone proximate prior to performing step (a).

10. The method of claim 1, wherein the geomechanical stress of the zone proximate in step (b) is increased from the reduced geomechanical stress in the zone proximate after first performing step (a), to a geomechanical stress level in the zone proximate that is greater than the geomechanical stress level in the zone proximate prior to previously performing step (a) in the zone proximate.

11. The method of claim 1, wherein the geomechanical stress of the zone proximate in step (a) is decreased from the increased geomechanical stress in the zone proximate after first performing step (b), to a geomechanical stress level in the zone proximate that is less than the geomechanical stress level in the zone proximate prior to previously performing step (a) in the zone proximate.

12. A method for fracturing a subterranean formation, comprising:
using a wellbore to perform one of the steps of;

(a) reducing the geomechanical stress in a zone proximate to the subterranean formation to translate a geomechanical stress change to the subterranean formation to cause a mechanical dislocation of at least a portion of the subterranean formation and create fractures within at least a portion of the subterranean formation; and

(b) applying stress in the zone proximate to the subterranean formation to translate a geomechanical stress change to the subterranean formation to cause a mechanical

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dislocation of at least a portion of the subterranean formation and create fractures within at least a portion of the subterranean formation; and

thereafter, using the wellbore to perform the other of step (a) and step (b).

13. The method of claim 12, wherein the subterranean formation comprises a hydrocarbon formation.

14. The method of claim 12, wherein the zone proximate comprises a formation layer in an underburden.

15. The method of claim 12, wherein step (a) creates a volumetric decrease in bulk volume of the zone proximate and the volumetric decrease is caused by a decrease in pore pressure within the zone proximate.

16. The method of claim 12, wherein step (b) creates a volumetric increase in bulk volume of the zone proximate and the volumetric increase is caused by an increase in pore pressure within the zone proximate.

17. The method of claim 15, wherein the decrease in pore pressure results in subsidence of the subterranean formation.

18. The method of claim 12, wherein step (a) creates a volumetric decrease in the zone proximate and the volumetric decrease is effected by a method that comprises pumping a fluid into the zone proximate to create a chemical reaction that reduces bulk volume of the zone proximate.

19. The method of claim 18, wherein the chemical reaction comprises chemicals which dissolve regions of the zone.

20. The method of claim 18, wherein the chemical reaction comprises and endothermic reaction that contracts the zone.

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21. The method of claim 12, wherein step (a) creates a volumetric decrease in the zone proximate and the volumetric decrease is effected producing fluid from the zone proximate.

22. The method of claim 12, wherein creating the volumetric decrease comprises material excavation from the zone proximate.

23. The method of claim 22, wherein the excavation within the zone proximate comprises at least one of introduction of abrasive fluids into the zone proximate, creating a wellbore tunnel within the zone proximate, collapsing a wellbore within the zone proximate, creating perforation tunnels within the zone proximate, leaching a soluble material from the zone proximate, dissolving soluble material from the zone proximate, gasification of material from the zone proximate, and eroding formation material from the zone proximate.

24. The method of claim 12, further comprising producing a hydrocarbon from the subterranean formation.

25. The method of claim 12, further comprising producing a geothermally heated fluid from the subterranean formation.

26. A method for production of a hydrocarbon from a hydrocarbon bearing formation, comprising:

cycling a contraction and expansion of a zone proximate to a hydrocarbon bearing subterranean formation to mechanically stress the hydrocarbon bearing subterranean formation and create an arch in the hydrocarbon bearing subterranean formation; and
creating a relative movement across a fracture surface to enhance conductivity;

27. The method of claim 26, wherein the hydrocarbon bearing subterranean formation comprises a tight gas reservoir.

28. The method of claim 26, wherein the hydrocarbon bearing subterranean formation comprises a shale gas reservoir.

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29. The method of claim 26, wherein the hydrocarbon bearing subterranean formation comprises a coal bed methane reservoir.
30. The method of claim 26, wherein the hydrocarbon bearing subterranean formation comprises a tight oil reservoir.
31. The method of claim 26, further comprising cycling the contraction of the zone proximate by reducing the in-situ stress in the zone proximate so as to cause at least a portion of the subterranean formation to arch in a direction toward the zone proximate..
32. The method of claim 26, further comprising cycling the expansion of the zone proximate by applying stress to the zone proximate so as to cause at least a portion of the subterranean formation to arch in a direction away from the zone proximate.
33. The method of claim 26, wherein the relative movement across a fracture surface creates a stimulated formation volume
34. The method of claim 32, further comprising producing a hydrocarbon from the hydrocarbon bearing subterranean formation.
35. The method of claim 32, comprising drilling a production well from the stimulation well into the hydrocarbon bearing subterranean formation.
36. The method of claim 26, further comprising drilling a production well into the hydrocarbon bearing subterranean formation after the treatment is completed.
37. The method of claim 26, further comprising drilling a production well into the hydrocarbon bearing subterranean formation before the treatment is completed.
38. The method of claim 26, further comprising where the cycling cause the zone to rubblize a layer of material along a delamination joint with the hydrocarbon bearing subterranean formation.
39. A hydrocarbon production system, comprising:
a hydrocarbon bearing subterranean formation;

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a zone proximate to the hydrocarbon bearing subterranean formation;
a stimulation well drilled to the zone; and
a stimulation system configured to comprise:
 creating a volumetric decrease; and
 reversing the volumetric decrease; and
 repeating the volumetric decrease for one or more cycles.

40. The hydrocarbon production system of claim 39, wherein the hydrocarbon bearing subterranean formation comprises a tight gas layer.

41. The hydrocarbon production system of claim 39, wherein the hydrocarbon bearing subterranean formation comprises a shale gas layer.

42. The hydrocarbon production system of claim 39, wherein the hydrocarbon bearing subterranean formation comprises a coal bed methane layer.

43. The hydrocarbon production system of claim 39, wherein the hydrocarbon bearing subterranean formation comprises a tight oil layer.

44. The hydrocarbon production system of claim 39, wherein the zone comprises a formation layer in an underburden.

45. The hydrocarbon production system of claim 39, comprising a production well drilled into the hydrocarbon bearing subterranean formation.

46. The hydrocarbon production system of claim 39, comprising a production well drilled into the hydrocarbon bearing subterranean formation from the stimulation well.

47. A method for fracturing a subterranean formation, comprising:
 causing a volumetric decrease in a zone proximate the subterranean formation so as to apply a geomechanical stress change to the subterranean formation, wherein the geomechanical stress change creates an arch-like bending movement in at least a portion of the subterranean formation and causes fractures to form in the subterranean formation;

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reversing the volumetric decrease in the zone proximate to cause a volumetric increase in the zone proximate so as to at least partially reverse the geomechanical stress change in the subterranean formation; and

thereafter repeating the volumetric decrease in the zone proximate to cause further fracturing in the subterranean formation.

48. The method of claim 47, wherein the caused fractures within the subterranean formation are caused through delamination of rock layers within the subterranean formation during arching of the subterranean formation.

49. The method of claim 47, further comprising changing stress in the zone proximate to cause at least a portion of the subterranean formation to arch in a direction away from the zone proximate.

50. The method of claim 47, further comprising changing stress in the zone proximate to cause at least a portion of the subterranean formation to arch in a direction toward the zone proximate.

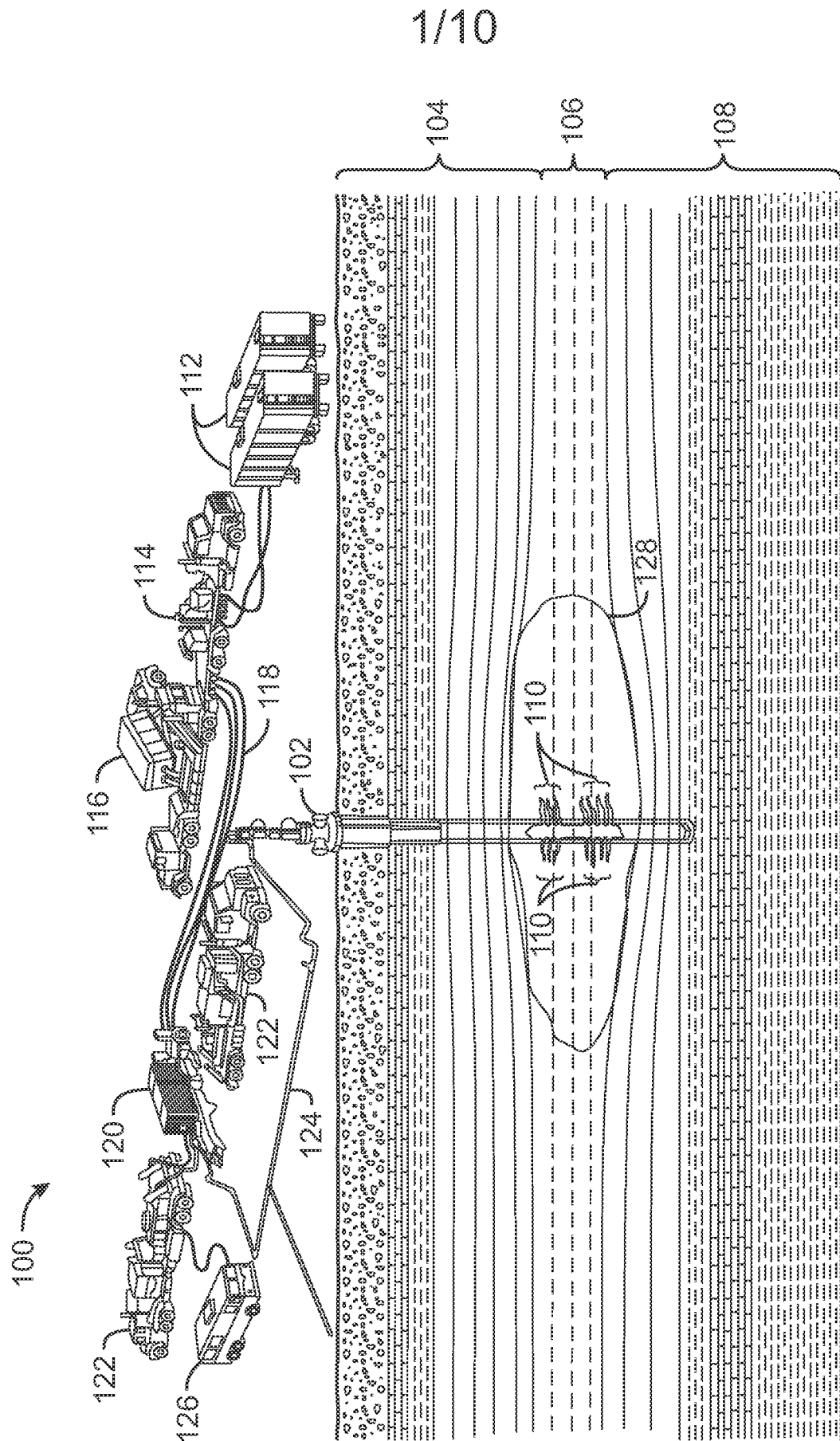
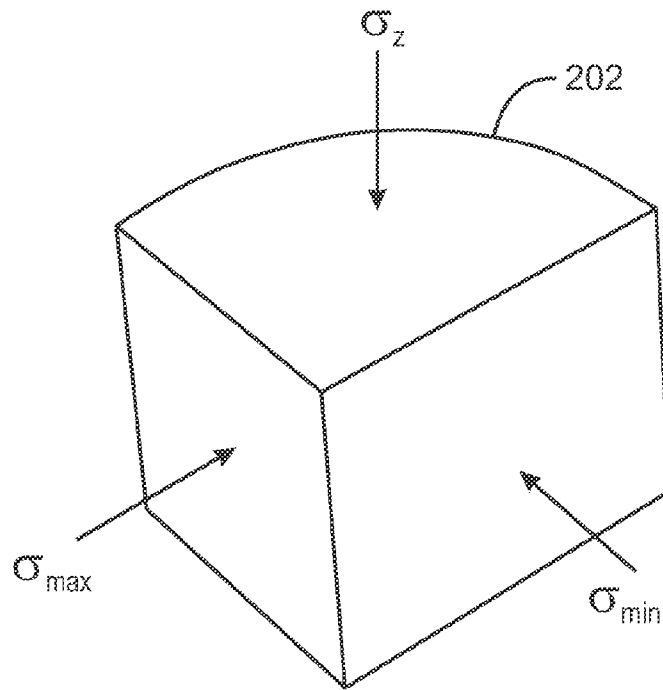


FIG. 1 (PRIOR ART)

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200
FIG. 2

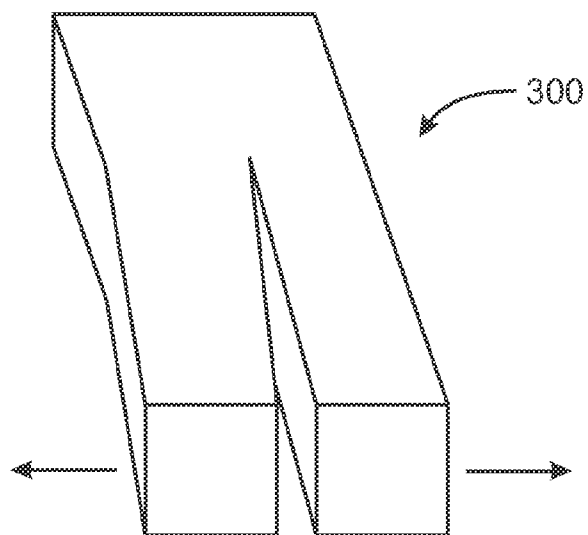
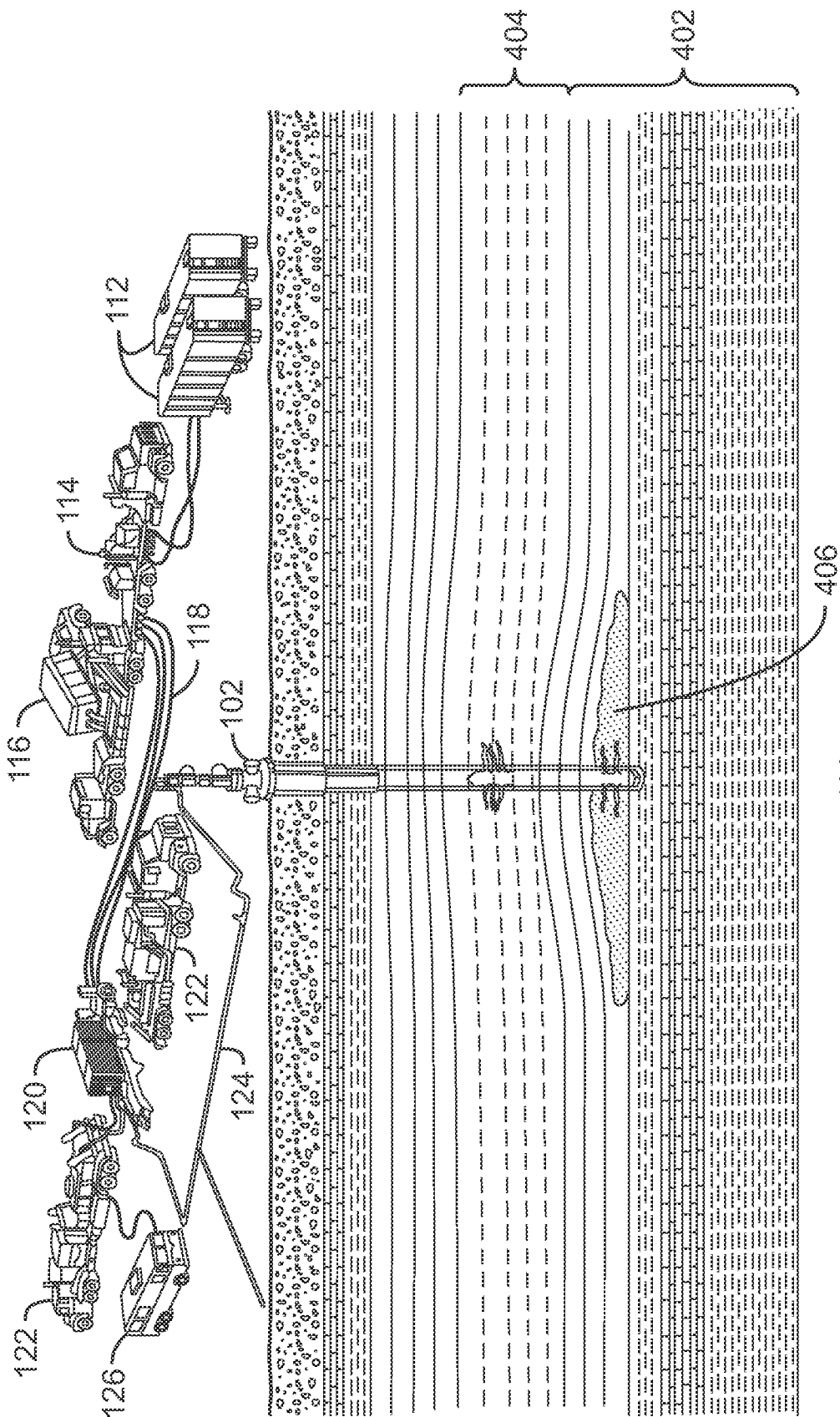


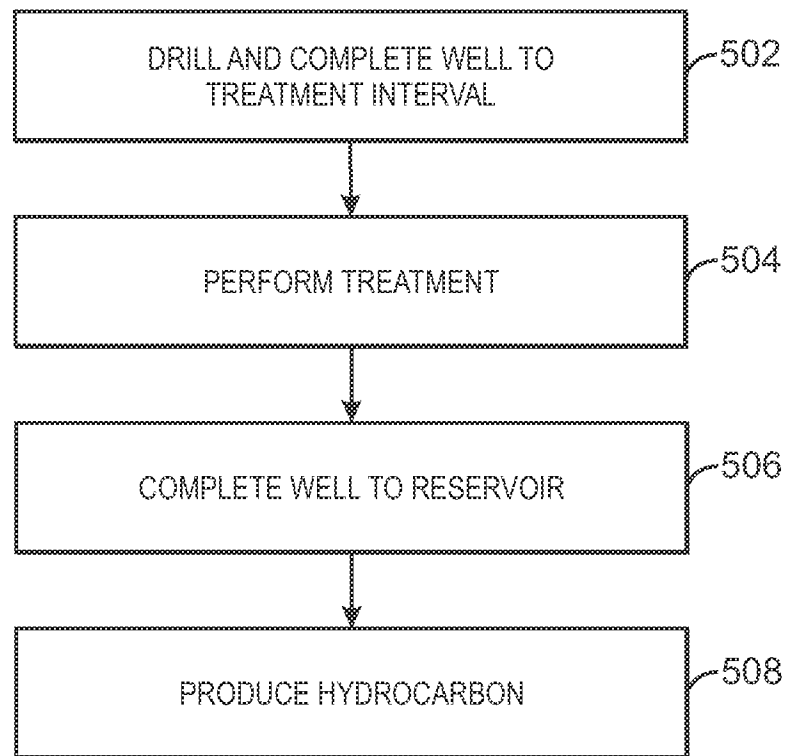
FIG. 3

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400
FIG. 4

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500
FIG. 5

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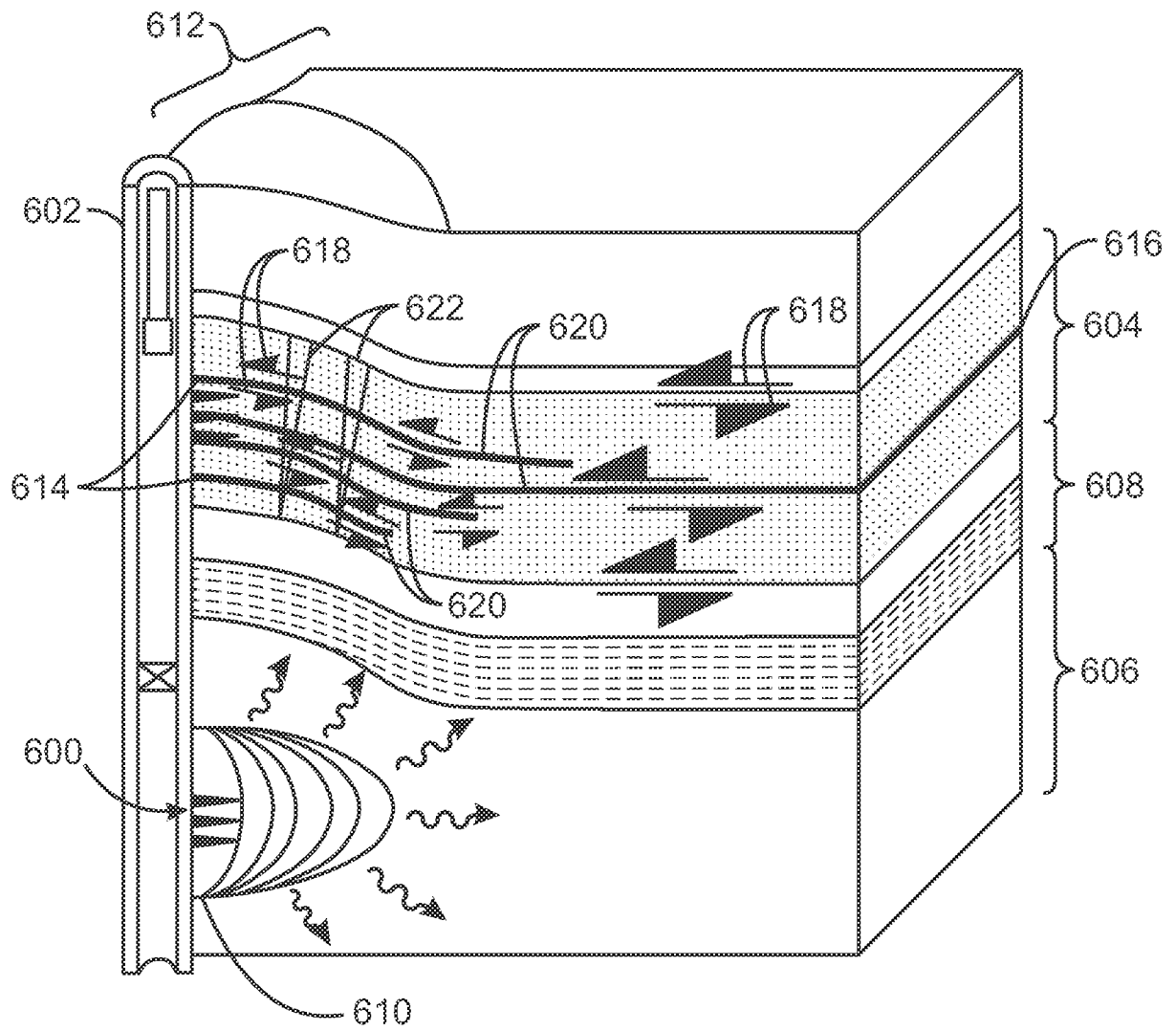


FIG. 6A

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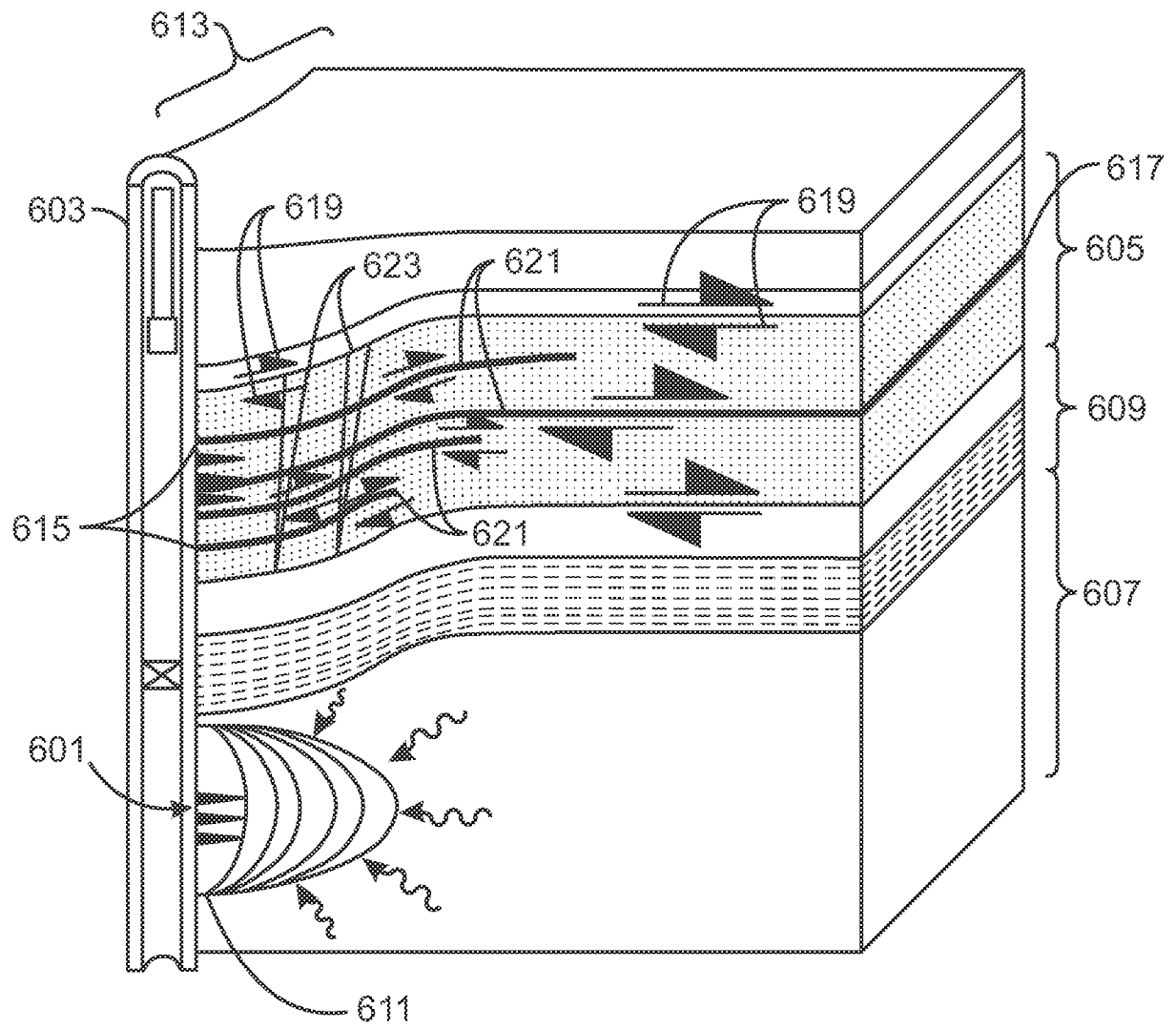
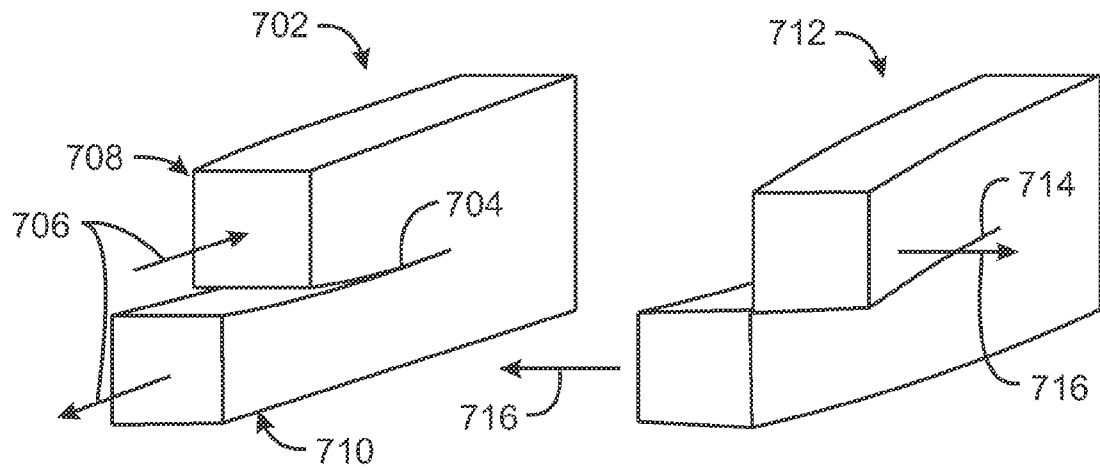
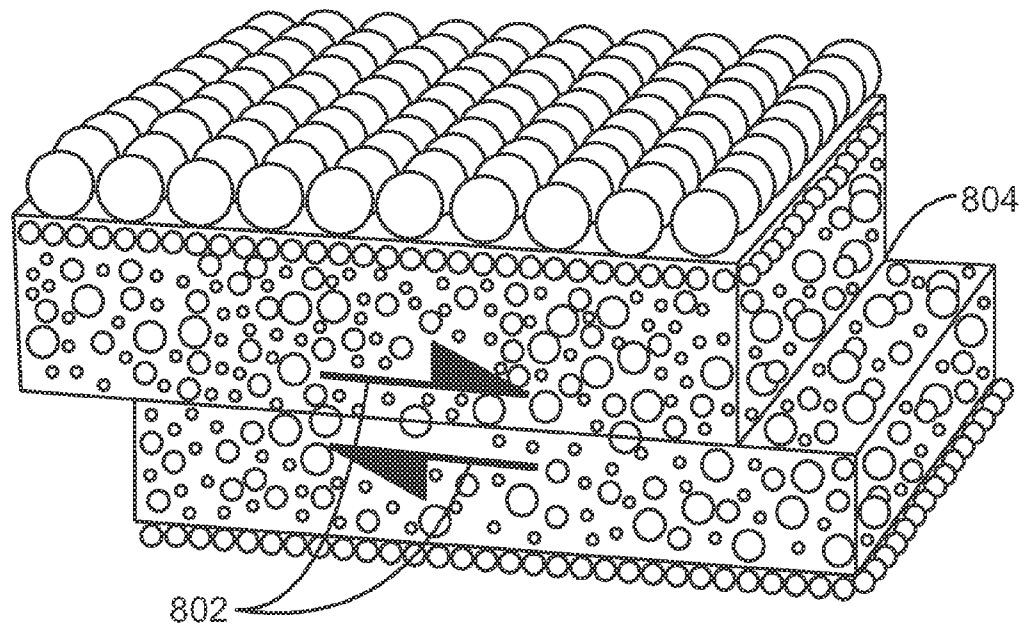


FIG. 6B

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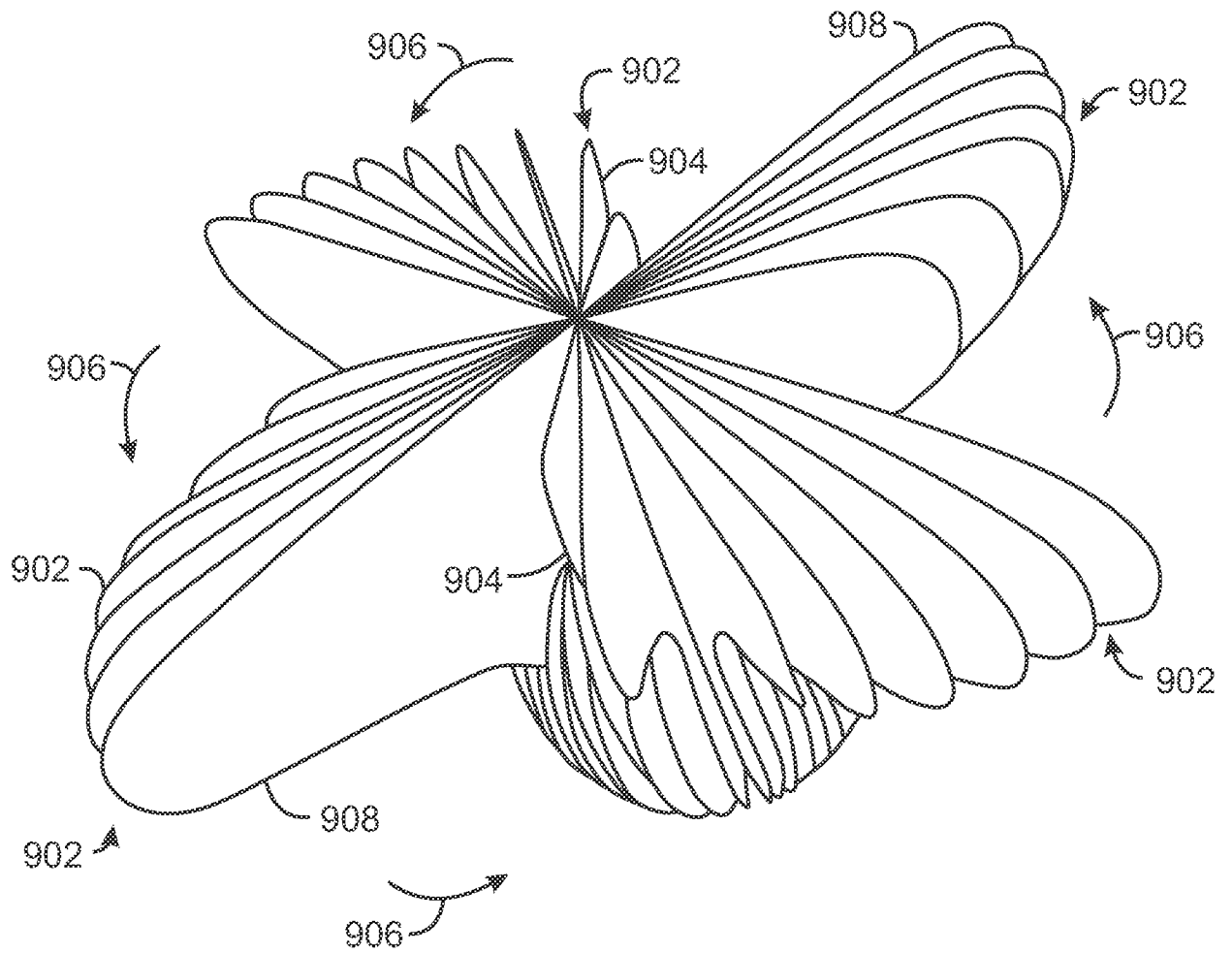


700
FIG. 7



800
FIG. 8

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900
FIG. 9

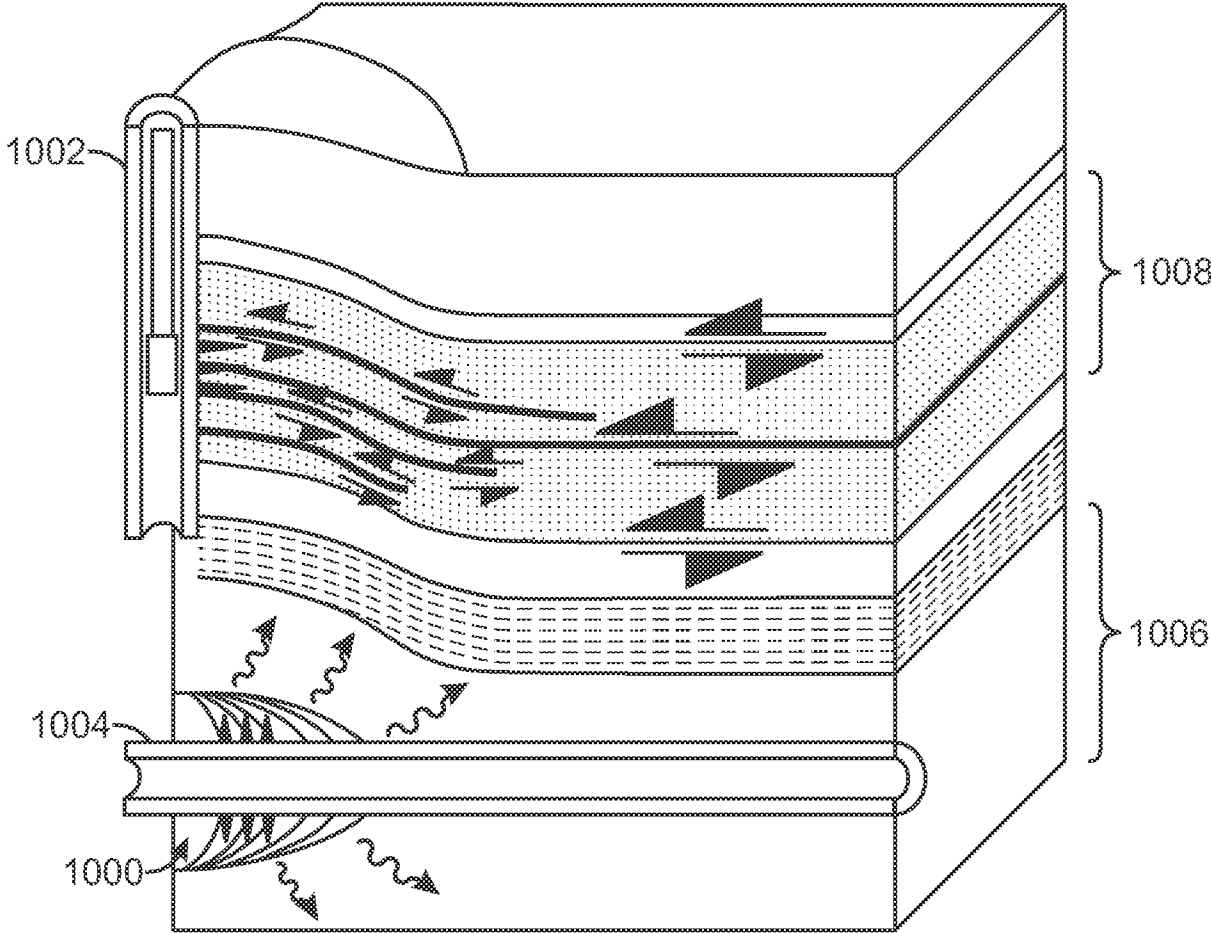


FIG. 10A

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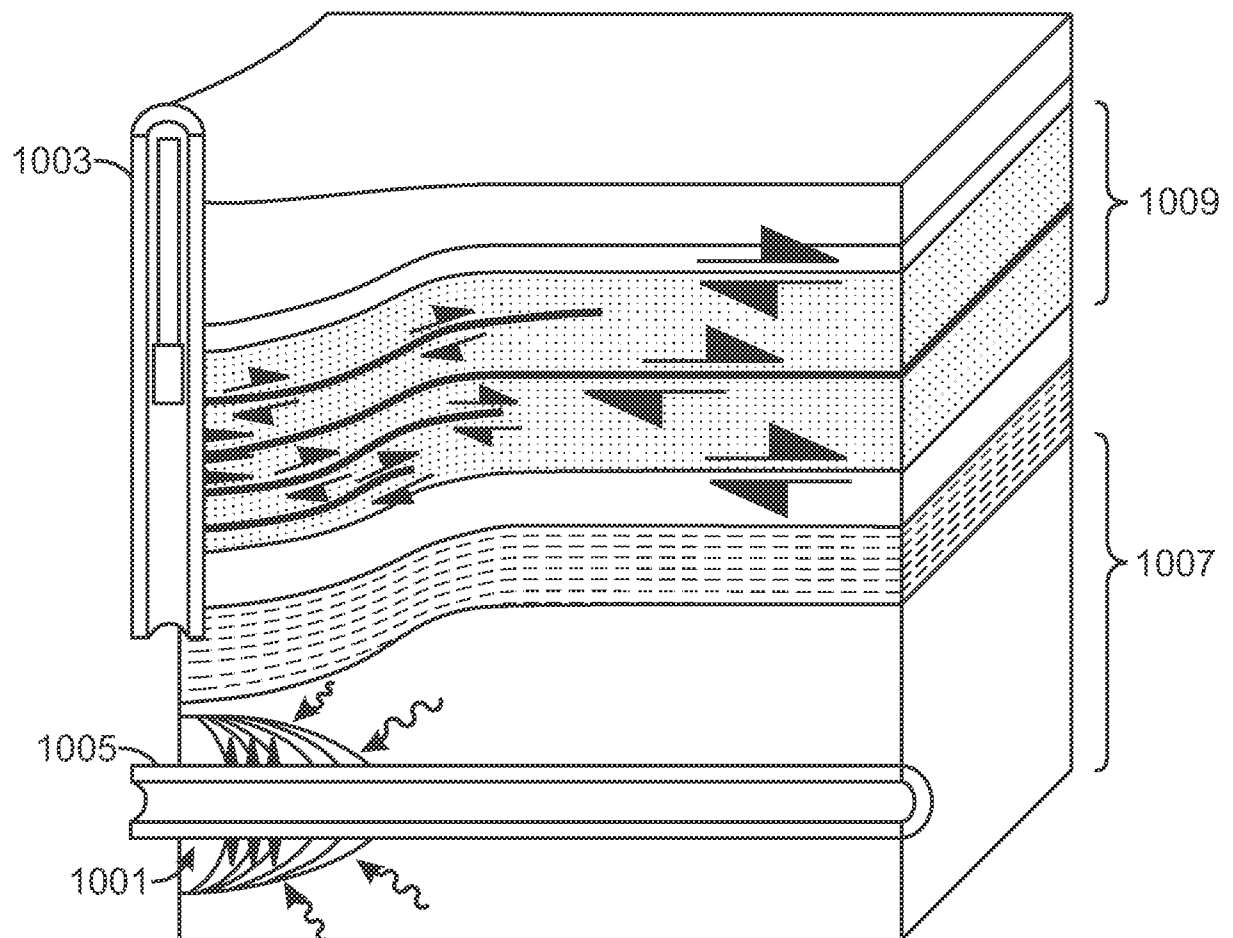


FIG. 10B

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2011/056348

A. CLASSIFICATION OF SUBJECT MATTER IPC(8) - E21B 43/26 (2012.01) USPC - 166/263 According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) IPC(8) - E21B 43/16, 43/25, 43/26 (2012.01) USPC - 166/263, 271 Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) PatBase		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 3,220,475 A (BRANDON) 30 November 1965 (30.11.1965) entire document	1-17, 21, 24-50
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Y		18-20, 22, 23
Y	US 3,063,499 A (ALLEN) 13 November 1962 (13.11.1962) entire document	18-20
Y	US 2007/0039729 A1 (WATSON et al) 22 February 2007 (22.02.2007) entire document	22, 23
☐ Further documents are listed in the continuation of Box C. ☐		
* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search 21 February 2012		Date of mailing of the international search report 29 FEB 2012
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201		Authorized officer: Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774