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(54) Title: ENHANCED HYDROCARBON FLUID RECOVERY VIA FORMATION COLLAPSE

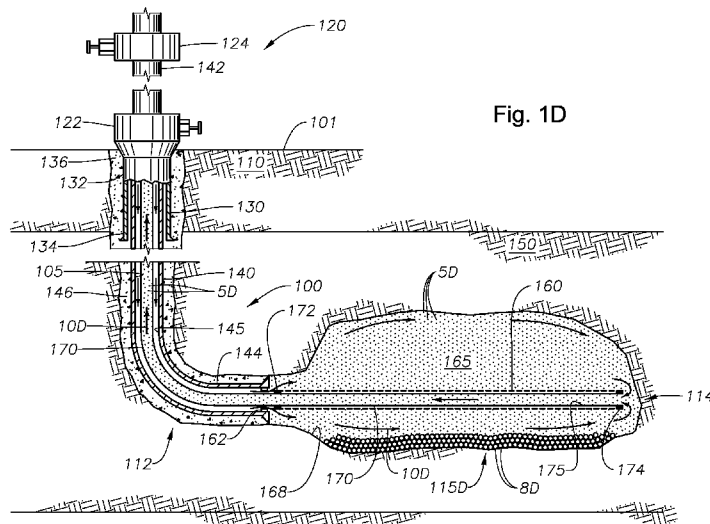


Fig. 1D

(57) Abstract: Methods for improving hydrocarbon production from a subsurface formation, such as a low-permeability formation, are provided herein. The methods may involve drilling a wellbore into the subsurface formation, and analyzing a mineralogy of a rock matrix making up the formation. The methods also include continuing to drill the wellbore into the formation, and running a working string into the wellbore and down to the formation. A first fluid is selected that will chemically produce a disaggregation or other change in the rock matrix. The methods then include circulating the first fluid across the formation. This serves to break off rock material from the formation and enlarge an annular region around the working string. Preferably, the wellbore operations induce at least a partial collapsing of the wellbore and a change in in situ stresses. This creates a fracture network within the subsurface formation, further aiding in the production of hydrocarbon fluids.



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ENHANCED HYDROCARBON FLUID RECOVERY VIA FORMATION COLLAPSE

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the priority benefit of U.S. Provisional Patent Application
5 61/369,484 filed 30 July 2010 entitled Enhanced Hydrocarbon Fluid Recovery Via Formation
Collapse, the entirety of which is incorporated by reference herein.

BACKGROUND

[0002] This section is intended to introduce various aspects of the art, which may be
associated with exemplary embodiments of the present disclosure. This discussion is
10 believed to assist in providing a framework to facilitate a better understanding of particular
aspects of the present disclosure. Accordingly, it should be understood that this section
should be read in this light, and not necessarily as admissions of prior art.

Field

[0003] The present inventions relate to the field of hydrocarbon recovery operations.
15 More specifically, the inventions relate to methods for increasing the permeability of shale
and other low-permeability formations in order to improve the recovery of hydrocarbon
fluids.

General Discussion of Technology

[0004] In the drilling of oil and gas wells, a wellbore is formed using a drill bit that is
20 urged downwardly at a lower end of a drill string. After drilling to a predetermined depth,
the drill string and connected bit are removed and the wellbore is lined with a string of
casing. An annular area is thus formed between the string of casing and the formation.

[0005] A cementing operation is typically conducted in order to fill or “squeeze” the
annular area with cement. This serves to form a cement sheath. The combination of cement
25 and casing strengthens the wellbore and facilitates the isolation of the formations behind the
casing.

[0006] It is common to place several strings of casing having progressively smaller outer
diameters into the wellbore. Thus, the process of drilling and then cementing progressively
smaller strings of casing is repeated several or even multiple times until the well has reached
30 total depth. The final string of casing, referred to as a production casing, is cemented into

place. In some instances, the final string of casing is a liner, that is, a string of casing that is not tied back to the surface, but is hung from the lower end of the preceding string of casing.

[0007] In some instances, a well may be completed as an open-hole completion. This means that the final tubular body run into the wellbore is not cemented into place; instead, a
5 perforated or "slotted" liner may be installed. Where the formation comprises an unconsolidated sand or other loosely-held rock matrix, a sand screen with a gravel pack may be placed along hydrocarbon-bearing intervals.

[0008] In some instances, a wellbore is completed in a formation having very low permeability. The low permeability may be less than 10 millidarcies, or even less than 5
10 millidarcies. In recent years, large accumulations of hydrocarbons have been discovered in such formations, even with a permeability that is less than 2 millidarcies. For example, the Barnett shale in northern Texas by some estimates holds recoverable gas reserves in the range of 26 to 39 trillion cubic feet.

[0009] Shale formations such as the Barnett shale are typically made up of fine-grained,
15 sedimentary rocks and significant amounts of clay minerals. These rocks typically have a native permeability of less than even 1 millidarcy. To extract hydrocarbon fluids from these or other low-permeability formations at commercial rates, it is usually necessary to increase the gross permeability of the hydrocarbon-bearing formation through hydraulic fracturing.

[0010] Hydraulic fracturing is a formation stimulation technique in which fluid is
20 pumped into the formation at a pressure higher than the minimum earth stress. The fracturing fluid is typically mixed with a proppant material such as sand, ceramic beads, or other granular material. The proppant serves to hold the fracture(s) open after the hydraulic pressures are released. The fracturing process creates fractures within the formation that allow formation fluids to more easily flow to the well.

[0011] In addition to hydraulic fracturing, operators may complete wells in low-
25 permeability formations in a highly deviated orientation. This substantially increases the wellbore surface area through a selected zone of interest. In one example, the operator may drill a well through a zone of interest in a substantially horizontal orientation, and then perform multiple fracture jobs along the horizontal portion using so-called slick-water. Slick
30 water is water with a viscosity-reducing agent added. This completion method can enable initial well rates for shale formations in the range of 3 to 10 million cubic feet per day (mcf/d).

[0012] While this method is considered useful in optimizing initial production rates, published estimates indicate that this method sometimes only recovers between 5% and 20% of the available gas. This is due to the inability of fracture cracks to create fluid communication channels across more than a small portion of the hydrocarbon reservoir.

5 Rates and recovery factors for shale formations are much lower than those typically achieved in conventional gas resources.

[0013] Another problem that has been encountered with hydraulic fracturing of low-permeability formations is that some shale strata are very ductile. Such shales have a tendency to close back around fractures after they are formed in response to *in situ* earth stress. The result is that wells completed in shale strata may experience a rapid decline in production. Decline rates for some shale gas wells have exceeded 50% per year.

10 [0014] Yet another problem with hydraulic fracturing is that it typically requires large volumes of water. A typical shale fracturing job may use more than 500,000 gallons of water. While some of this water is returned when the well is initially put on production, a significant fraction (such as up to 40%) is normally lost downhole. This is particularly problematic and expensive in areas where water may not be abundant.

[0015] Finally, the completion and stimulation technology used to generate multiple fractures is expensive, often comprising more than 50% of the well construction costs.

20 [0016] A need exists for a method to enhance the flow capacity of low-permeability reservoirs without a primary reliance on hydraulic fracturing. A need further exists for a method of increasing the surface area of the wellbore face to enhance exposure to the surrounding formation.

SUMMARY OF THE INVENTION

25 [0017] Methods for improving hydrocarbon production from a subsurface formation are provided herein. The methods have application to wells that are completed as open-holes in formations having low permeability. In one example, the wells have a permeability of less than 10 millidarcies. The wells may be completed either vertically, or as deviated holes. However, the methods have greatest utility in improving recovery efficiency in wells that are completed substantially horizontally.

30 [0018] In one aspect, the method first includes drilling a wellbore using a drill string. The wellbore is drilled into a subsurface formation. The method may also include analyzing

a mineralogy of a rock matrix making up the formation. In one aspect, the rock matrix comprises shale.

5 [0019] The method may also include continuing to drill the wellbore through the subsurface formation. Preferably, the drill string extends to proximate a bottom portion of the subsurface formation. A working string is then run into the wellbore. The working string extends into the subsurface formation, and forms an annulus (circular or other shape) between the working string and the surrounding formation. Optionally, a pre-perforated liner is also installed along the bottom portion of the wellbore before running the working string into the wellbore.

10 [0020] The method further includes selecting a fluid as a first fluid. The first fluid is selected so as to induce via chemical interaction (i) a swelling of the rock matrix, (ii) a disaggregation of the rock matrix, (iii) a dissolution of particles within the rock matrix, or (iv) combinations thereof. In this way, the first fluid acts against the rock matrix to enlarge the annulus along at least a bottom portion of the subsurface formation.

15 [0021] The first fluid may comprise, for example, fresh water. Alternatively, the first fluid may be an organic solvent. Alternatively still, the first fluid may include a detergent, an acidic fluid, an oxygen-releasing compound, or a bleaching compound. The first fluid is selected based on the analysis of the mineralogy of the rock matrix.

20 [0022] The method also includes flowing the first fluid across the subsurface formation within the wellbore. Preferably, flowing comprises reverse-circulating the first fluid into the annulus across the subsurface formation, and back up a bore of the working string to the surface. The chemical action of the first fluid breaks off rock material from the bottom portion of the subsurface formation and enlarges the annulus. Typically, the first fluid is pressurized in the bottom portion of the wellbore to a pressure greater than initial pore pressure in the shale, but less than a fracture initiation pressure.

25 [0023] In one aspect, the method includes continuing to flow the first fluid until enough rock material is broken off from the bottom portion of the subsurface formation to change *in situ* stresses within the subsurface formation. This, in turn, (i) induces at least partial collapse of the bottom portion of the wellbore, and (ii) creates a fracture network within the subsurface formation above the collapsed bottom portion of the wellbore.

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[0024] The method further includes producing hydrocarbon fluids from the subsurface formation. In a preferred embodiment, the hydrocarbon fluids comprise primarily gaseous hydrocarbons that are produced through a pre-perforated liner.

5 [0025] In one aspect, the method also includes circulating a cleaning fluid into the annulus across the subsurface formation. The action of the cleaning fluid removes at least a portion of the rock material that has broken off. The cleaning fluid may have substantially the same composition as the first fluid, in which case the cleaning fluid is a chemically reactive fluid. Alternatively, the cleaning fluid may have a composition that is different from the first fluid. In the latter instance, the cleaning fluid preferably contains a viscosifier to
10 increase fluid density and to facilitate the transport of rock material up the bore of the working string during circulating.

[0026] Additional steps may be taken to further induce the bottom portion of the wellbore to collapse. In one approach, the operator may reduce fluid pressure within the open-hole portion of the wellbore. The fluid pressure is reduced, for example, by reverse circulating a
15 collapsing fluid into the deviated portion of the wellbore, wherein the collapsing fluid has a density that is less than a density of the first fluid. The collapsing fluid may comprise, for example, a gas or a light hydrocarbon fluid. In another approach, the operator may further induce the bottom portion of the wellbore to collapse by changing the temperature of the bottom portion of the formation. For example, the temperature of the bottom portion of the
20 formation may be increased by at least 100° F.

[0027] Yet additional steps may be taken to enlarge the annulus in the open-hole portion of the wellbore. For example, nozzles may be run into the end of the working string. The first fluid may then be jetted against the rock matrix. Alternatively, the first fluid may be oscillated within the wellbore.

25 [0028] A method for improving hydrocarbon production from a subsurface formation is also provided herein. The method again has application to wells that are completed as open-holes in formations having low permeability.

[0029] In one aspect, the method first includes drilling a wellbore into the subsurface formation. Drilling is conducted using a drill string and connected drill bit. The method also
30 includes selecting a first fluid which chemically interacts with the rock matrix adjacent to the wellbore to weaken the rock matrix. The first fluid is selected based on a mineralogy of the

rock matrix. Thus, the method may optionally include analyzing a mineralogy of the rock matrix making up the formation. In one aspect, the rock matrix comprises primarily shale.

[0030] The method further comprises flowing the first fluid into the wellbore and across the subsurface formation. In this manner, the first fluid contacts the rock matrix along the subsurface formation adjacent to the wellbore. This serves to weaken the rock matrix.

[0031] The method then includes withdrawing the drill string from the subsurface formation. Withdrawal may mean only partially raising the drill string to a depth above the subsurface formation. More preferably, withdrawal means tripping the drill string from the hole, and then attaching a new rock grinding device before re-entry.

[0032] In operation, the first fluid may be flowed down an annulus formed between the drill string so as to break off rock material from the rock matrix along the subsurface formation. This also serves to radially enlarge at least a portion of the wellbore along the subsurface formation. In one aspect, the first fluid chemically interacts with the rock matrix to cause a swelling of the rock matrix. Alternatively or in addition, the first fluid chemically interacts with the rock matrix to cause a dissolution of inorganic particles within the rock matrix. Alternatively or in addition, the first fluid chemically interacts with the rock matrix to cause a dissolution of organic binders within the rock matrix.

[0033] To facilitate flowing the first fluid across the subsurface formation, the method may include running a working string into the wellbore. The working string extends into the subsurface formation and forms an annulus between the working string and the surrounding formation. In this instance, flowing the first fluid comprises circulating the first fluid through the annulus.

[0034] The action of flowing the first fluid across the subsurface formation serves to break off at least some rock material. The rock material falls into the wellbore. Thus, the method preferably also includes rotating the drill string and a connected rock grinding device back along the subsurface formation to grind out at least a portion of the broken rock material. The rock grinding device may be, for example, another drill bit or an auger. During this clean-out process, a cleaning fluid is circulated through the drill string. The cleaning fluid may be the first fluid, but preferably it is a drilling mud or heavy fluid that can transport rock particles away from the subsurface formation and up the wellbore.

[0035] In one aspect, a collapsing fluid is placed in the wellbore after the first fluid is circulated across the subsurface formation. The collapsing fluid is a foam, a gas, or other

low-density fluid. The collapsing fluid may or may not be circulated across the subsurface formation. In either instance, the collapsing fluid induces further collapse of the rock matrix into the wellbore. Thereafter, the drill string and a connected rock grinding device are rotated back along the subsurface formation to grind out at least a portion of newly broken rock material. In addition, the cleaning fluid is circulated through the drill string to at least partially clean out the wellbore.

[0036] The steps of weakening and/or collapsing and/or drilling and cleaning may be repeated. Hydrocarbons are then produced from the subsurface formation.

BRIEF DESCRIPTION OF THE DRAWINGS

[0037] So that the present inventions can be better understood, certain drawings, charts, graphs and/or flow charts are appended hereto. It is to be noted, however, that the drawings illustrate only selected embodiments of the inventions and are therefore not to be considered limiting of scope, for the inventions may admit to other equally effective embodiments and applications.

[0038] Figure 1A is a cross-sectional view of an illustrative wellbore. The wellbore has been completed substantially horizontally as an open-hole completion. A working string is placed within a slotted liner along a hydrocarbon-bearing formation.

[0039] Figure 1B is a next cross-sectional view of the wellbore of Figure 1A. Here, a first fluid is being reverse-circulated through the wellbore. The volume of the annulus at the open-hole portion of the wellbore is being increased, and material from the rock matrix is being circulated out of the wellbore.

[0040] Figure 1C is a next cross-sectional view of the wellbore of Figure 1A. The first fluid continues to be reverse-circulated through the wellbore, causing the volume of the annulus at the open-hole portion of the wellbore to be further increased.

[0041] Figure 1D is a next cross-sectional view of the wellbore of Figure 1A. The open-hole portion of the wellbore is being induced to collapse.

[0042] Figure 1E is a next cross-sectional view of the wellbore of Figure 1A. The working string is being incrementally withdrawn from the wellbore, and rock material continues to be circulated out of the open-hole portion of the wellbore. A network of fractures is also seen in the subsurface formation.

[0043] Figure 1F is a next cross-sectional view of the wellbore of Figure 1A. Here, the working string has been removed, and compressible hydrocarbon fluids are being produced from the subsurface formation.

5 [0044] Figure 2A is a cross-sectional view of an illustrative wellbore, in an alternate arrangement. The wellbore has been completed substantially vertically as an open-hole completion. A working string is placed within a slotted liner along a hydrocarbon-bearing formation.

[0045] Figure 2B is a next cross-sectional view of the wellbore of Figure 2A. Here, a first fluid is being reverse-circulated through the wellbore. The volume of the annulus at the
10 open-hole portion of the wellbore is being increased, and material from the rock matrix is being circulated out of the wellbore.

[0046] Figure 2C is a next cross-sectional view of the wellbore of Figure 2A. The first fluid continues to be reverse-circulated through the wellbore, causing the volume of the annulus at the open-hole portion of the wellbore to be further increased.

15 [0047] Figure 2D is a next cross-sectional view of the wellbore of Figure 2A. The open-hole portion of the wellbore is being induced to collapse.

[0048] Figure 2E is a next cross-sectional view of the wellbore of Figure 2A. Here, a coiled tubing has been run into the wellbore with a nozzle, and fluid is being jetted against the formation face to further enlarge the annulus around the open-hole portion of the
20 wellbore.

[0049] Figure 2F is a next cross-sectional view of the wellbore of Figure 2A. A network of fractures is seen in the subsurface formation as a result of inducing the wellbore to collapse.

[0050] Figure 2G is a next cross-sectional view of the wellbore of Figure 2A. Here, the
25 working string has been removed, and compressible hydrocarbon fluids are being produced from the subsurface formation.

[0051] Figure 3 is a flowchart demonstrating steps of a method for improving hydrocarbon production from a subsurface formation.

DETAILED DESCRIPTION OF CERTAIN EMBODIMENTS**Definitions**

[0052] As used herein, the term “hydrocarbon” refers to an organic compound that includes primarily, if not exclusively, the elements hydrogen and carbon. Hydrocarbons generally fall into two classes: aliphatic, or straight chain hydrocarbons, and cyclic, or closed ring, hydrocarbons, including cyclic terpenes. Examples of hydrocarbon-containing materials include any form of natural gas, oil, coal, and bitumen that can be used as a fuel or upgraded into a fuel.

[0053] As used herein, the term “hydrocarbon fluids” refers to a hydrocarbon or mixtures of hydrocarbons that are gases or liquids. For example, hydrocarbon fluids may include a hydrocarbon or mixtures of hydrocarbons that are gases or liquids at formation conditions, at processing conditions, or at ambient conditions (15° C and 1 atm pressure). Hydrocarbon fluids may include, for example, oil, natural gas, coal bed methane, shale oil, pyrolysis oil, pyrolysis gas, a pyrolysis product of coal, and other hydrocarbons that are in a gaseous or liquid state.

[0054] As used herein, the term “fluid” refers to gases, liquids, and combinations of gases and liquids, as well as to combinations of gases and solids, and combinations of liquids and solids.

[0055] As used herein, the term “condensable hydrocarbons” means those hydrocarbons that condense at about 15° C and one atmosphere absolute pressure. Condensable hydrocarbons may include, for example, a mixture of hydrocarbons having carbon numbers greater than 4.

[0056] As used herein, the term “subsurface” refers to geologic strata occurring below the earth's surface.

[0057] As used herein, the term “formation” refers to any definable subsurface region. The formation may contain one or more hydrocarbon-containing layers, one or more non-hydrocarbon containing layers, an overburden, and/or an underburden of any geologic formation.

[0058] The terms “zone” or “zone of interest” refer to a portion of a formation containing hydrocarbons.

[0059] The terms "annulus" and "annular region" mean a region between a tubular body within a wellbore and a surrounding tubular body or a surrounding formation. The annulus or annular region need not be precisely circular, or precisely shaped as a ring, but generally refer to a gap of any shape.

5 [0060] As used herein, the term "wellbore" refers to a hole in the subsurface made by drilling or insertion of a conduit into the subsurface. A wellbore may have a substantially circular cross section, or other cross-sectional shape. As used herein, the term "well", when referring to an opening in the formation, may be used interchangeably with the term "wellbore."

10 [0061] The term "tubular member" refers to any pipe, such as a joint of casing, a portion of a liner, a sand screen, or a pup joint.

Description of Selected Specific Embodiments

[0062] The inventions are described herein in connection with certain specific embodiments. However, to the extent that the following detailed description is specific to a particular embodiment or a particular use, such is intended to be illustrative only and is not to be construed as limiting the scope of the inventions.

[0063] Certain aspects of the inventions are also described in connection with various figures. In the figures, the top of the drawing page is intended to be toward the surface, and the bottom of the drawing page toward the well bottom. While wells commonly are completed in substantially vertical orientation, it is understood that wells may also be inclined and even horizontally completed. When the descriptive terms "up and down" or "upper" and "lower" or similar terms are used in reference to a drawing, they are intended to indicate relative location on the drawing page, and not necessarily orientation in the ground, as the present inventions have utility no matter how the wellbore is orientated.

25 [0064] **Figure 1A** is a cross-sectional view of an illustrative wellbore **100**. The wellbore **100** principally defines a bore **105** that extends from a surface **101**, and into the earth's subsurface **110**. The wellbore **100** also includes a wellhead **120** at the surface **101**. The wellhead **120** contains various items of flow control equipment such as a lower master fracturing valve **122** and an upper master fracturing valve **124**. It is understood that the wellhead **120** will include additional valves and other components, such as a blow-out preventer, used for drilling and completing a well. Once the well is completed, a well tree will be installed for directing the flow of production fluids.

[0065] The wellbore **100** has been completed by setting a series of pipes into the subsurface **110**. These pipes include a first string of casing **130**, sometimes known as surface casing or a conductor. The surface casing **130** has an upper end **132** in sealed connection with the lower master fracture valve **122**. The surface casing **130** also has a lower end **134**.
5 The surface casing **130** is secured in the subsurface **110** with a surrounding cement sheath **136**. The combination of the surface casing **130** and the cement sheath **136** strengthens the wellbore **100** and facilitates the isolation of formations behind the casing **130**.

[0066] The pipes also include one or more sets of intermediate casing **140**. The illustrative intermediate casing **140** also has an upper end **142** in sealed connection with the
10 upper master fracture valve **124**. The intermediate casing **140** also has a lower end **144**. The intermediate casing **140** is secured in the subsurface **110** with a surrounding cement sheath **146**. It is understood that a wellbore may, and typically will, include more than one string of intermediate casing. Some of the intermediate casing strings may be only partially cemented into place, depending on regulatory requirements and the presence of migratory fluids in any
15 adjacent strata.

[0067] In some completions, a final string of casing, referred to as a production casing is installed. This string is likewise cemented into place, and then perforated in order to provide fluid communication between hydrocarbon fluids within the surrounding subsurface formation and the bore of the wellbore. However, in **Figure 1A**, the wellbore **100** is being
20 completed as an open-hole completion. This means that a string of production casing is not run into the wellbore and cemented into place; rather, a bottom portion of the wellbore **100** is exposed to a hydrocarbon-bearing formation **150**. This represents an open-hole portion **115A**.

[0068] There are certain advantages to open-hole completions versus cased-hole
25 completions. First, because open-hole completions have no perforation tunnels, formation fluids can converge on the wellbore radially 360 degrees. This has the benefit of eliminating the additional pressure drop associated with converging radial flow and then linear flow through particle-filled perforation tunnels. The reduced pressure drop associated with an open-hole completion virtually guarantees that it will be more productive than an
30 unstimulated, cased hole in the same formation.

[0069] Second, open-hole completions, including gravel pack techniques, are oftentimes less expensive than cased hole completions. For example, the use of perforated liners and

gravel packs eliminates the need for cementing, perforating, and post-perforation clean-up operations.

5 [0070] In **Figure 1A**, the wellbore **100** has been drilled into a hydrocarbon-bearing formation **150**. More specifically, the wellbore **100** has been completed substantially horizontally within the hydrocarbon-bearing formation **150**. The horizontal (or deviated) portion of the wellbore **100** is largely within the open-hole portion **115A** of the wellbore **100**. In this instance, the open-hole portion **115A** extends from proximate a heel **112** of the wellbore **100** to a toe **114**.

10 [0071] In order to support the open-hole portion **115A** and to receive production fluids, a slotted liner **160** is optionally placed within the open-hole portion **115A** of the wellbore **100**. The slotted liner **160** is connected to the bottom **144** of the intermediate string of casing **140** using a liner hanger **162**. The liner **160** may be connected proximate the heel **112** of the open-hole portion **115**, and preferably extends to the toe **114** of the wellbore **100**.

15 [0072] A working string **170** is also placed along the hydrocarbon-bearing formation **150**. The working string **170** resides within the slotted liner **160**. The working string **170** may be, for example, a string of coiled tubing. Upper **172** and lower **174** packers serve as fluid diversion means around the working string **170**. In one aspect, a first fluid is pumped down an annular region **145** between the working string **170** and the surrounding casing **140**. The first fluid is then directed by the upper packer **172** to circulate around the slotted liner **160** and against the formation face along the open-hole portion **115A**. The first fluid is then returned up a bore **175** of the working string **170**.

25 [0073] The arrangement of a working string **170** within a slotted liner **160** shown in **Figure 1A** provides for what is known as “reverse-circulating.” However, it is understood that the operator may optionally use forward-circulating. In that instance, a working fluid is pumped down the bore **175** of the working string **170**, to the heel **114** of the open-hole portion **115A** of the wellbore **100**, and then up the annulus **145**. In addition, the operator may choose to circulate fluid using the working string **170** before installing the slotted liner **160**. In that instance, packers **172** and **174** would not be needed.

30 [0074] **Figure 1B** is a next cross-sectional view of the wellbore **100** of **Figure 1A**. A first fluid is being reverse-circulated through the wellbore **100**. The flow of the first fluid is seen at arrows **10B**.

[0075] The first fluid is selected with the idea of interacting with the rock matrix making up the hydrocarbon-bearing formation **150**. More specifically, the first fluid is selected to induce a swelling of the rock matrix. Alternatively or in addition, the first fluid is selected to induce a chemical disaggregation of the rock matrix. Alternatively or in addition, the first fluid is selected to induce a dissolution of particles within the rock matrix.

[0076] Various fluids may be selected to accomplish one or more of these affects. For example, the first fluid may be an organic solvent. Examples of an organic solvent include methanol, ethanol, propanol, iso-propanol, terpenes, and diesel. Alternatively, the first fluid may comprise a detergent. An example of a suitable detergent is a quaternary ammonium compound. Solvents and detergents may be beneficial in breaking up a formation which contains solid or near-solid hydrocarbons which act as binders between inorganic rock particles. Such hydrocarbons may include kerogen, bitumen, coal, or pyrobitumen. Another type of fluid that might be selected is a surfactant. Surfactants may facilitate the attack of water on certain shale components by lowering the surface tension of the water.

[0077] As another example, the first fluid may be an acidic fluid. For example, the acidic fluid may comprise at least 10% by volume hydrochloric acid, acetic acid, or formic acid. Alternatively still, the first fluid may comprise an oxygen-releasing compound. Suitable examples of oxygen-releasing compounds include hydrogen peroxide, sodium perborate, sodium percarbonate, sodium persulfate, tetrasodium pyrophosphate, and urea peroxide. Acidic fluids and oxygen-releasing compounds may be beneficial in causing shale and clay-based formations to swell and break up. They may further be beneficial in causing carbonate formations to dissolve.

[0078] A further example for a first fluid is fresh water or other water having a salt content of less than about 1% by mass. Due to their clay content and composition, some low-permeability shale formations are sensitive to water, and will swell. Upon swelling, such formations become susceptible to breaking apart or disaggregation when exposed to fluid circulation.

[0079] As yet another example, the first fluid may include a bleaching compound. Examples of a bleaching compound are sodium hypochlorite and calcium hypochlorite. Bleaching compounds may be beneficial where the rock matrix making up the formation contains solid or near-solid hydrocarbons which act as binders between inorganic rock particles. Such hydrocarbons may include kerogen, bitumen, coal, or pyrobitumen. In any event, selection of the first fluid is based on the mineralogy of the rock matrix in the

hydrocarbon-bearing formation **150**. “Mineralogy” in this context is understood to include solid-like organics in addition to inorganic solids.

5 [0080] As the first fluid is circulated, it will react with the rock matrix in the subsurface formation. Portions of the rock matrix may chemically interact with the first fluid, changing the fluid’s pH. Therefore, in connection with circulating the first fluid, the first fluid may be pH buffered. This means that the fluid is monitored to ensure that it has a consistent pH for dissolving or otherwise reacting with the rock matrix making up the formation **150**.

10 [0081] Returning to **Figure 1B**, it can be seen that an annulus **165** between the slotted liner **160** and the surrounding open-hole portion **115B** of the wellbore **100** has become enlarged relative to the original position of **Figure 1A**. This is due to interaction of the first fluid with the rock matrix. Particles **5B** representing material from the rock matrix are being removed from the open-hole portion **115B** of the wellbore **100**. The rock particles **5B** are being circulated through the bore **175** of the working string **170** and up to the surface **101**.

15 [0082] **Figure 1C** is a next cross-sectional view of the wellbore **100** of **Figure 1A**. The first fluid continues to be circulated through the wellbore **100**. In this instance, circulation is again reverse-circulating. The flow of the first fluid is seen at arrows **10C**.

20 [0083] Circulation of the first fluid causes the volume of the enlarged annulus **165** at the open-hole portion of the wellbore **100** to be further increased. The enlarged open-hole portion is now indicated at **115C**. Particles **5C** representing material from the rock matrix are being removed from the open-hole portion **115C** of the subsurface formation **100**. The rock particles **5C** are again being circulated through the bore **175** of the working string **170** and up to the surface **101**.

25 [0084] **Figure 1D** is a next cross-sectional view of the wellbore **100** of **Figure 1A**. Here, the open-hole portion **115D** of the wellbore **100** is being induced to collapse. Large formation particles **8D** are seen laying on the bottom of the annulus **165** in the open-hole portion **115D**.

30 [0085] The open-hole portion **115D** of the wellbore **100** may be induced to collapse in a number of different ways. For example, the operator may reduce fluid pressure within the open-hole portion **115D** of the wellbore **100**. The fluid pressure may be reduced, for example, by circulating a second fluid into the wellbore, wherein the second fluid has a density that is less than a density of the first fluid. In this instance, the second fluid is a collapsing fluid.

[0086] In **Figure 1D**, arrows **10D** indicate the circulation of a collapsing fluid. The collapsing fluid may comprise, for example, a gas or a light hydrocarbon fluid. Because the collapsing fluid has a density that is less than the density of the first fluid, the hydrostatic head will be reduced, allowing the open-hole portion **115D** to at least partially collapse.

5 Particles **8D** indicate formation particles that have fallen to the bottom of the annulus **165** as a result of the partial collapse.

[0087] It is understood that in actual practice, the enlarged annulus **165** in open-hole portion **115D** probably will not have the somewhat smooth mono-diameter appearance presented in **Figure 1D**. Further, it is understood that the annulus **165** presented in **Figure**

10 **1D** is not to scale. In actual practice, the annulus **165** may only be enlarged in diameter by about one to ten meters. Still further, it is understood that numerous additional particles **8D** may gather in the open-hole portion **115** of the wellbore **100**, and may even encompass the slotted liner **160**.

[0088] To further induce a collapse of the open-hole portion **115D** of the wellbore **100**,

15 the operator may further reduce the pressure within the open-hole portion **115D** of the wellbore **100** by reducing pressure of injection pumps (not shown) at the surface **101**. In these instances, the collapsing fluid may optionally have the same composition as the first fluid. Wellbore pressure is preferably reduced to below initial reservoir pressure. In addition, the operator may cause one or more oscillations in the fluid pressure. Oscillations

20 may be created by cyclically increasing and drawing down the wellbore pressure using a pump at the surface. Alternatively, oscillating the first fluid may be done by reciprocating a downhole plunger, or generating ultrasonic frequencies downhole. Such oscillations may occur infrequently or with a relatively slow frequency, for example less than 1 Hz, 0.01 Hz, or even 0.0001 Hz. Alternatively, high frequency oscillations may be propagated through the

25 fluid in the wellbore by generating ultrasonic frequencies downhole. Such frequencies may be in excess of, for example, about 10 kHz, and can enhance particle break-off from the wellbore surfaces.

[0089] As an alternative means of inducing a collapse of the open-hole portion **115D** of the wellbore **100**, the temperature of the hydrocarbon-bearing formation **150** may be changed.

30 For example, the temperature of the hydrocarbon-bearing formation **150** adjacent to the wellbore may be increased by at least 100° F. Depending on the mineralogy of the rock matrix, changing the temperature may cause the rock matrix to become more susceptible to dissolution and/or disaggregation when exposed to the first fluid, the second fluid, or both.

[0090] The temperature of at least a portion of the hydrocarbon-bearing formation **150** may be increased by circulating a heated fluid through the working string **170**. The heated fluid may be, for example, steam. Alternatively, the temperature of at least a portion of the formation **150** may be increased by actuating a downhole electrical resistance heater. This
5 may be done, for example, by running a conductive member into the wellbore adjacent the hydrocarbon-bearing formation **150**, and then running a current through the conductive member to generate resistive heat. Where the working string **170** is a string of coiled tubing, the coiled tubing should ideally be removed from the wellbore **170** before the resistive heat is generated to avoid melting or deformity.

10 [0091] **Figure 1E** is a next cross-sectional view of the wellbore **100** of **Figure 1A**. In this view, the particles **8D** that fell from the formation **150** are being optionally removed. To do this, the first or second fluid continues to be circulated through the wellbore **100**. Arrows **10E** indicate the direction of the flow of fluid. At the same time, the working string **170** is incrementally withdrawn from the wellbore **100**. In **Figure 1E**, the working string **170** is
15 withdrawn to position **E₁**.

[0092] Continuing to circulate the fluid as indicated by arrows **10E** will also cause further erosion of the formation **150** and increase the size of the annulus **165**. Particles **5E** continue to break away from the hydrocarbon-bearing formation **150**. The particles **5E** are seen being moved from the annulus **165**, up the bore **175** of the working string **170**, and to the surface
20 **101**.

[0093] As an aid in transporting rock particles **5E** to the surface, the second fluid may have a viscosity that is greater than a viscosity of the first fluid. In this instance, the second fluid is a cleaning fluid. In one aspect, a viscosifier is added to the cleaning fluid to increase the density and the viscosity of the cleaning fluid so as to assist in the transport of rock
25 particles **5E**. In another aspect, a collapsing fluid is used, followed by a cleaning fluid.

[0094] The working string **170** will be withdrawn from the open-hole portion **115E** of the wellbore **100** to subsequent positions. These positions will include positions **E₂** and **E₃**. As the working string **170** is withdrawn from the open-hole portion **115E** and as fluid continues to be circulated, at least some of the particles **5E** are cleaned out of the wellbore **100**.
30 Moreover, as the annulus **165** is enlarged due to the removal of material from the formation **150**, the *in situ* stresses within the formation **150** change. This, in turn, creates a network of fractures **155**.

[0095] **Figure 1F** is a next cross-sectional view of the wellbore **100** of **Figure 1A**. Here, the working string **170** has been completely removed from the wellbore **100**. The wellbore **100** has been put on production. Hydrocarbon fluids are being produced from the formation **150**, into the perforated liner **160**, and to the surface **101**. In the illustrative view of **Figure**
5 **1F**, the hydrocarbon fluids are light hydrocarbon fluids such as methane. Methane gas production is indicated by bubbles **180**.

[0096] **Figures 1A** through **1F** demonstrate one way of increasing the surface area of a wellbore **100** so as improve hydrocarbon recovery. This approach may desirably change *in situ* stresses within a subsurface formation **150**, causing fracturing to take place with the
10 subsurface formation **150** and provide increased flow paths for valuable hydrocarbon fluids. The wellbore **100** is completed as a deviated wellbore.

[0097] **Figures 2A** through **2G** demonstrate an alternative way of improving hydrocarbon recovery from a subsurface formation. In these figures, a wellbore **200** is shown. The wellbore **200** is completed as a substantially vertical wellbore.

[0098] First, **Figure 2A** is a cross-sectional view of the illustrative wellbore **200**. The wellbore **200** principally defines a bore **205** that extends from a surface **201**, and into the earth's subsurface **210**. As with wellbore **100**, the wellbore **200** also includes a wellhead **120** at the surface **101**. These again include various items of flow control equipment such as a lower master fracturing valve **122** and an upper master fracturing valve **124**. It is understood
15 that the wellhead **120** will include additional valves and other components, such as a blow-out preventer, used for drilling and completing a well. Once the well is completed, a well tree will be installed for directing the flow of production fluids.

[0099] The wellbore **200** has been completed by setting a series of pipes into the subsurface **210**. These pipes include a first string of casing **230**, sometimes known as surface casing or a conductor. The surface casing **230** has an upper end **232** in sealed connection
25 with the lower master fracture valve **122**. The surface casing **230** also has a lower end **234**. The surface casing **230** is secured in the subsurface **210** with a surrounding cement sheath **236**. The combination of the surface casing **230** and the cement sheath **236** strengthens the wellbore **200** and facilitates the isolation of formations behind the casing **230**.

[0100] The pipes also include one or more sets of intermediate casing **240**. The illustrative intermediate casing **240** also has an upper end **242** in sealed connection with the upper master fracture valve **124**. The intermediate casing **240** also has a lower end **244**. The
30

intermediate casing **240** is secured in the subsurface **210** with a surrounding cement sheath **246**. It is understood that a wellbore may, and typically will, include more than one string of intermediate casing. Some of the intermediate casing strings may be only partially cemented into place, depending on regulatory requirements and the presence of migratory fluids in any adjacent strata.

[0101] As with wellbore **100**, the wellbore **200** is being completed as an open-hole completion. This again means that a string of production casing is not run into the wellbore and cemented into place; rather, a bottom portion of the wellbore **200** is exposed to a hydrocarbon-bearing formation **250**. An open-hole portion of the wellbore **200** of **Figure 2A** is seen at **215A**.

[0102] In **Figure 2A**, the wellbore **200** has been drilled into a hydrocarbon-bearing formation **250**. More specifically, the wellbore **200** has been completed substantially vertically within the hydrocarbon-bearing formation **250**. The open-hole portion **215A** of the wellbore **200** is along the hydrocarbon-bearing formation **250**.

[0103] In order to receive production fluids, a slotted liner **260** is optionally placed within the open-hole portion **215A** of the wellbore **200**. The slotted liner **260** is connected to the bottom **244** of the intermediate string of casing **240** using a liner hanger **262**. The liner **260** preferably extends near the bottom of the wellbore **200**.

[0104] A working string **270** is also placed along the hydrocarbon-bearing formation **250**. The working string **270** resides within the slotted liner **260**. The working string **270** may be, for example, a string of coiled tubing. Upper **272** and lower **274** packers serve as fluid diversion means around the working string **270**. A first fluid is pumped down an annular region **145** between the working string **270** and the surrounding casing **240**. The first fluid is then directed by the upper packer **272** to circulate around the slotted liner **260** and against the formation face **215A**. The first fluid is then returned up a bore **275** of the working string **270**.

[0105] The arrangement of a working string **270** within the slotted liner **260** shown in **Figure 2A** provides for reverse-circulation. However, it is again understood that the operator may optionally use forward-circulation. In that instance, a working fluid is pumped down the bore **275** of the working string **270**, to the bottom of the wellbore **200**, and then up the annulus **245**. In addition, the operator may choose to circulate fluid using the working string **270** before installing the slotted liner **260**.

[0106] **Figure 2B** is a next cross-sectional view of the wellbore **200** of **Figure 2A**. A first fluid is being reverse-circulated through the wellbore **200**. The flow of the first fluid is seen at arrows **10B**.

5 [0107] The first fluid is once again selected with the idea of interacting with the rock matrix making up the hydrocarbon-bearing formation **250**. More specifically, the first fluid is selected to induce a swelling of the rock matrix. Alternatively or in addition, the first fluid is selected to induce a disaggregation of the rock matrix. Alternatively or in addition, the first fluid is selected to induce a dissolution of particles within the rock matrix.

10 [0108] As discussed above in connection with **Figure 1B**, various fluids may be selected to accomplish one or more of these affects. Those fluids again may be fresh water, an acid solution, a bleaching compound, a solvent, a detergent, or other fluid. Selection of the first fluid is based upon an analysis of the mineralogy of the rock matrix in the hydrocarbon-bearing formation **250**.

15 [0109] As the first fluid is circulated, it will react with the rock matrix in the subsurface formation **250**. Portions of the rock matrix may chemically interact with the first fluid, changing the fluid's pH. Therefore, in connection with circulating the first fluid, the first fluid may be pH buffered. This means that the fluid is monitored to ensure that it has a consistent pH for dissolving or otherwise reacting with the rock matrix making up the subsurface formation **250**. Additionally or alternatively, when the interaction between the
20 first fluid and the rock matrix is not dependent solely on the pH of the first fluid, the composition of the first fluid may be monitored in other manners to ensure substantially consistent composition. For example, when the first fluid is fresh water, the salinity of the water may be monitored.

25 [0110] Returning to **Figure 2B**, it can be seen that an annulus **265** between the slotted liner **260** and the surrounding open-hole portion **215B** of the wellbore **100** has become enlarged relative to the original position of **Figure 2A**. This is due to interaction of the first fluid with the rock matrix. The flow of the first fluid is seen at arrows **10B**. Particles **5B** representing material from the rock matrix are being removed from the open-hole portion **215B** of the subsurface formation **210**. The rock particles **5B** are being circulated through the
30 bore **275** of the working string **270** and to the surface **201**.

[0111] **Figure 2C** is a next cross-sectional view of the wellbore **200** of **Figure 2A**. The first fluid continues to be circulated through the wellbore **200**. In this instance, circulation is again reverse-circulation. The flow of the first fluid is seen at arrows **10C**.

5 [0112] Circulation of the first fluid causes the volume of the enlarged annulus **265** at the open-hole portion of the wellbore **200** to be further increased. The enlarged open-hole portion is now indicated at **215C**. Particles **5C** representing material from the rock matrix are being removed from the open-hole portion **215C** of the subsurface formation **100**. The rock particles **5C** are being circulated through the bore **275** of the working string **270** and to the surface **201**.

10 [0113] **Figure 2D** is a next cross-sectional view of the wellbore **200** of **Figure 2A**. Here, the open-hole portion of the wellbore **200** is being induced to collapse. The collapsing open-hole portion is now shown at **215D**. Formation particles **8D** are seen collecting on the bottom of the annulus **165** in the open-hole portion **215D**.

15 [0114] The open-hole portion **215D** of the wellbore **100** may be induced to collapse in a number of different ways. For example, the operator may reduce fluid pressure within the open-hole portion **215D** of the wellbore **200**. The fluid pressure may be reduced, for example, by circulating a collapsing fluid into the wellbore, wherein the collapsing fluid has a density that is less than a density of the first fluid.

20 [0115] In **Figure 2D**, arrows **10D** indicate the circulation of a second fluid. As noted above, the second fluid may be a collapsing fluid that comprises, for example, a gas or a hydrocarbon fluid. The collapsing fluid will have a density that is less than the density of the first fluid so as to reduce the hydrostatic head and allow the open-hole portion **215D** to at least partially collapse. Particles **8D** indicate formation particles that have fallen to the bottom of the annulus **265** as a result of the partial collapse.

25 [0116] It is again understood that in actual practice, the enlarged annulus **265** probably will not have the somewhat smooth appearance presented in **Figure 2D**. Further, it is understood that the annulus presented at **265** is not to scale. In actual practice, the annulus **265** may only be enlarged in diameter by about one to five meters. Still further, it is understood that numerous additional particles **8D** may gather in the open-hole portion **215D**
30 of the wellbore **100**, and may even encompass at least a bottom portion of the slotted liner **260**.

[0117] To further induce a collapse of the open-hole portion **215D** of the wellbore **100**, the operator may further reduce the pressure within the open-hole portion **215D** of the wellbore **100**. by reducing pressure of injection pumps (not shown) at the surface **201**. In these instances, the second fluid may optionally have the same composition as the first fluid.

5 Wellbore pressure is preferably reduced to below initial reservoir pressure. In addition, the operator may cause one or more oscillations in the fluid pressure. Oscillations may be created by cyclically increasing and drawing down the wellbore pressure using a pump at the surface. Alternatively, oscillating the first fluid may be done by reciprocating a downhole plunger. Such oscillations may occur infrequently or with a relatively slow frequency, for
10 example, less than 1 Hz, 0.01 Hz, or even 0.0001 Hz. Alternatively, high frequency oscillations may be propagated through the fluid in the wellbore by generating ultrasonic frequencies downhole. Such frequencies may be in excess of, for example, about 10 kHz, and can enhance particle break-off from the wellbore surfaces.

[0118] As an alternative means of inducing a collapse of the open-hole portion **215** of the
15 wellbore **200**, the temperature of the formation **250** may be changed. For example, the temperature of the subsurface formation **250** may be increased by at least 100° F. Depending on the mineralogy of the rock matrix, changing the temperature may cause the rock matrix to become more susceptible to dissolution and/or disaggregation when exposed to either the first or the second fluid.

20 [0119] **Figure 2E** is a next cross-sectional view of the wellbore of **Figure 2A**. Here, a string of coiled tubing **290** has been run into the wellbore **200**. More specifically, the string of coiled tubing **290** has been run into the bore **275** of the working string **270**. The coiled tubing string **290** has a nozzle **292** at its lower end. The nozzle **292** is positioned below the slotted liner **260**. Hydraulic fluid is being pumped from the surface **201** and through the
25 nozzle **292**. Jets of hydraulic fluid, seen at **294**, are being directed against the hydrocarbon-bearing formation **250** in order to further enlarge at least a bottom portion of the annulus **265**.

[0120] It is noted that the operator may choose to remove the original working string **270** from the wellbore **200** before running in the string of coiled tubing **290**. Further, the operator may choose to use the original working string **270** for running in the nozzle **292**. In this
30 instance, the nozzle **292** would actually be attached to a bottom end of the original working string **270**. The working string **270** would then be re-run into the wellbore **200** for the hydraulic jetting operation. In any respect, the step of jetting hydraulic fluid against the hydrocarbon-bearing formation shown in **Figure 2E** is optional.

[0121] An open-hole portion of the wellbore **200** is shown in **Figure 2E** at **215E**. It can be seen that the volume of the open-hole portion **215E** is being further increased due to the hydraulic forces being applied to the hydrocarbon-bearing formation **250**. The hydraulic forces cause additional particles **8E** to fall from the rock matrix making up the hydrocarbon-bearing formation **250**.

[0122] **Figure 2F** is a next cross-sectional view of the wellbore **200** of **Figure 2A**. In this view, the particles **8D** and **8E** that fell from the formation **250** have been optionally removed. To do this, the second fluid continues to be circulated through the wellbore **200**. Preferably, the second fluid is a cleaning fluid that has a higher viscosity than the first fluid in order to carry larger formation particles **8E**. Arrows **10F** indicate the direction of the flow of fluid. At the same time, the working string **270** is incrementally withdrawn from the wellbore **200**.

[0123] Continuing to circulate the cleaning fluid as indicated by arrows **10F** will also cause further erosion of the formation **250** and increase the size of the annulus **265**. Particles **5F** continue to break away from the subsurface formation **250**. The particles **5F** are seen being moved from the annulus **265**, up the bore **275** of the working string **270**, and to the surface **201**.

[0124] As an aid in transporting rock particles **5F** to the surface, the second fluid may have a viscosity that is greater than a viscosity of the first fluid. In this instance, the second fluid is a cleaning fluid. In one aspect, a viscosifier is added to the cleaning fluid to increase the density and the viscosity of the fluid so as to assist in the transport of rock particles **5F**.

[0125] As the annulus **265** is enlarged due to the removal of material from the hydrocarbon-bearing formation **250**, the *in situ* stresses within the formation **250** change. This, in turn, creates a network of fractures **255**. The fractures **255** provide fluid pathways for hydrocarbon fluids en route to the wellbore **200** during later production.

[0126] **Figure 2G** is a next cross-sectional view of the wellbore **200** of **Figure 2A**. Here, the working string **270** has been removed from the wellbore **200**. The wellbore **200** has been put on production. Hydrocarbon fluids are being produced from the subsurface formation **250**, into the perforated liner **260**, and to the surface **201**.

[0127] In the illustrative view of **Figure 2G**, the hydrocarbon fluids are again light hydrocarbon fluids such as methane. Methane gas production is indicated by bubbles **280**. The flow of gas bubbles **280** to the surface **201** is indicated by arrows **10G**.

[0128] It is noted that while production is shown taking place in the wellbore **200**, the operator may choose to treat the wellbore **200** as a permanent formation heater well, or perhaps convert the wellbore **200** to an injector for acid gas injection (“AGI”). In such instances, production of hydrocarbon fluids from the hydrocarbon-bearing formation **250** will
5 take place in one or more separate production wells. The operator will complete one or more separate wells as production wells, and then produce the hydrocarbon fluids from those separate wells. The same process for enlarging the annulus in an open-hole completion may be undertaken for the separate production wells.

[0129] **Figure 3** presents a flow chart for a method **300** for improving hydrocarbon
10 production from a subsurface formation. The method **300** has application to wells that are completed as open-hole completions. The method **300** has greatest benefit in hydrocarbon-bearing formations having low permeability. In one example, the subsurface formation has a permeability of less than 10 millidarcies.

[0130] The method **300** first includes drilling a wellbore into a subsurface formation.
15 This step is shown in Box **310**. The wellbore is drilled using a drill string with a connected drill bit. Preferably, and the wellbore is drilled through and to a bottom of the subsurface formation. The wellbore may be vertical, or it may be deviated. The method **300** has particular advantage in wells that are completed horizontally.

[0131] The method **300** may optionally include analyzing a mineralogy of the rock matrix
20 making up the subsurface formation. This is provided at Box **320**. In one aspect, the rock matrix comprises shale. As an example, the rock matrix may comprise greater than about 12 wt. % clay.

[0132] The drill string may serve as a working string for the method **300**. Optionally
25 though, the drill string is removed from the wellbore, and a separate working string is then run into the wellbore. This is shown at Box **330**. In either instance, the working string extends into the subsurface formation, and forms an annulus between the working string and the surrounding formation. Preferably, a separate working string is employed and a pre-perforated liner is also installed along the bottom portion of the wellbore before running the working string into the wellbore.

[0133] The method **300** further includes selecting a fluid as a first fluid. This is seen at
30 Box **340**. The first fluid is based on a mineralogy of the rock matrix. The first fluid is selected so as to chemically induce (i) a swelling of the rock matrix, (ii) a disaggregation of

the rock matrix, (iii) a dissolution of particles within the rock matrix, or (iv) combinations thereof. In this way, the first fluid acts against the rock matrix to enlarge the annulus or to at least loosen the rock matrix.

[0134] As noted above, the first fluid may comprise, for example, fresh water.

5 Alternatively, the first fluid may be an organic solvent. Alternatively still, the first fluid may include a detergent, an acidic fluid, an oxygen-releasing compound, or a bleaching compound. The operator will determine which of these fluids, or which combination of these fluids, has greatest utility in breaking up or removing particles from the rock matrix as the first fluid is circulated across the subsurface formation.

10 [0135] The method **300** also includes circulating or otherwise flowing the first fluid across the subsurface formation. This is seen at Box **350**. Circulating may mean traditional forward-circulation, but more preferably represents reverse-circulation. In reverse-circulation, the first fluid is injected into the annulus and then back up the bore of the working string. The chemical interaction of the first fluid breaks off rock material from the
15 bottom portion of the subsurface formation and enlarges the annulus. Typically, the first fluid is pressurized in the wellbore to a pressure greater than initial pore pressure in the shale, but less than a fracture initiation pressure.

[0136] In one aspect, the method **300** includes continuing to circulate or otherwise flow the first fluid until enough rock material is broken off from the bottom portion of the
20 subsurface formation to change *in situ* stresses within the subsurface formation. This, in turn, (i) induces at least partial collapse of the bottom portion of the wellbore, and (ii) creates a fracture network within the subsurface formation above the collapsed bottom portion of the wellbore. In one aspect, a volume of collapsed shale is at least 100 cubic meters.

[0137] It is noted that the process of flowing the first fluid in the method **300** may involve
25 flowing the first fluid through the drill string. In this instance, the drill string is maintained in the wellbore as the working string, with the first fluid being flowed into the wellbore. In one aspect, the first fluid is circulated across the subsurface formation for chemical interaction with the rock matrix. The first fluid may be flowed down an annulus formed between the drill string and the surrounding subsurface formation and up the drill string to a surface.
30 Alternatively, the first fluid may be flowed down the bore of the drill string, and up an annulus formed between the drill string and the surrounding subsurface formation. In either instance, this would be before the drill string is withdrawn from the subsurface formation. In

another aspect, the drill string is temporarily withdrawn from the subsurface formation during circulation.

5 [0138] Preferably, the drill string is reintroduced along the subsurface formation for further drilling of the formation to remove collapsed rock material, and for further circulation of the first fluid. A drill bit, an auger, or other mechanical device may be used for grinding the rock material. A weighted cleaning fluid is preferably circulated during this process. The cleaning fluid may be circulated down the annulus between the drill string and the surrounding subsurface formation, and back up the bore of the drill string.

10 [0139] In one aspect, the method **300** also includes circulating a second fluid into the annulus across the subsurface formation to remove at least a portion of the rock material that has broken off. This is provided at Box **360**. The second fluid may be a reactive fluid that has substantially the same composition as the first fluid, or it may be different from the first fluid. In the latter instance, the second fluid preferably contains a viscosifier to facilitate the transport of rock material up the bore of the working string during reverse-circulating. The
15 second fluid may thus be a cleaning fluid.

[0140] Additional steps may be taken to further induce the bottom portion of the wellbore to collapse. In one approach, the operator may reduce fluid pressure within the open-hole portion of the wellbore. This is seen at Box **370**. In one aspect, the fluid pressure is reduced by reverse circulating a second fluid into the deviated portion of the wellbore, where the
20 second fluid is a collapsing fluid that has a density that is less than a density of the first fluid. The collapsing fluid may comprise, for example, a gas or a light hydrocarbon fluid. In another approach, the operator may further induce the bottom portion of the wellbore to collapse by changing the temperature of the bottom portion of the formation. This is indicated at Box **375**. For example, the temperature of the portion of the formation
25 immediately adjacent to the wellbore may be increased by at least 100° F.

[0141] Yet additional steps may be taken to enlarge the annulus in the open-hole portion of the wellbore. For example, nozzles may be run into the end of the working string. The first fluid may then be jetted through the nozzles and against the rock matrix. Alternatively, the first fluid may be oscillated within the wellbore.

30 [0142] The method **300** further includes producing hydrocarbon fluids from the subsurface formation. The producing step is seen at Box **380**. In a preferred embodiment, the hydrocarbon fluids comprise primarily light hydrocarbons that are produced through a

pre-perforated liner. These would include methane and ethane. Of course, some acid gases may also be produced in the process.

5 [0143] The steps in the method related to enlarging the annulus or inducing a collapse of the wellbore may be repeated one or more times. In addition, the method 300 may further comprise running the drill string back into a bottom portion of the subsurface formation, and rotating the drill string and connected drill bit to grind out collapsed rock material. A cleaning fluid may be circulated through the drill string during this process.

10 [0144] The method 300 in its various embodiments provides a way to create a fracture network in a low-permeability formation. The method 300 takes advantage of hydraulic forces and chemical action working against the formation in order to change *in situ* stresses and intentionally induce wellbore collapse. While it will be apparent that the inventions herein described are well calculated to achieve the benefits and advantages set forth above, it will be appreciated that the inventions are susceptible to modification, variation and change without departing from the spirit thereof.

Claims

What is claimed is:

1. A method for improving hydrocarbon production from a subsurface formation, comprising:

5 drilling a wellbore from a surface into a subsurface formation;

running a working string into the wellbore, the working string extending into the subsurface formation, and forming an annulus between the working string and the surrounding formation;

10 based on an analysis of a mineralogy of a rock matrix making up the subsurface formation, selecting a fluid as a first fluid to induce, via chemical interaction, (i) a swelling of the rock matrix, (ii) a disaggregation of the rock matrix, (iii) a dissolution of particles within the rock matrix, or (iv) combinations thereof;

flowing the first fluid into the annulus across the subsurface formation in order to break off rock material from the subsurface formation and enlarge the annulus; and

15 producing hydrocarbon fluids from the subsurface formation.

2. The method of claim 1, further comprising:

circulating a cleaning fluid into the annulus across the subsurface formation to remove at least a portion of the rock material that has broken off.

20

3. The method of claim 2, wherein circulating the cleaning fluid comprises reverse-circulating the cleaning fluid into the annulus across the subsurface formation and back up the bore of the working string.

25 4. The method of claim 3, wherein the cleaning fluid contains a viscosifier to facilitate the transport of rock material up the bore of the working string during reverse-circulation.

5. The method of claim 1, further comprising:

running the drill string back into the subsurface formation;

30 drilling out broken rock material from the wellbore; and

circulating a cleaning fluid through a bore of the drill string to at least partially remove the broken rock material.

6. The method of claim 1, further comprising:
installing a pre-perforated liner along a bottom portion of the wellbore before running
the working string into the wellbore; and
wherein the hydrocarbon fluids are produced through the pre-perforated liner.

5

7. The method of claim 1, wherein:
the method further comprises injecting a fluid through the wellbore and into the
subsurface formation; and
producing hydrocarbon fluids from the subsurface formation comprises:
10 completing a production well separate from the wellbore; and
producing hydrocarbon fluids from the production well.

8. The method of claim 1, further comprising:
continuing to flow the first fluid until enough rock material is broken off from the
15 bottom portion of the subsurface formation to change *in situ* stresses within the subsurface
formation and induce at least partial collapse of the wellbore.

9. The method of claim 8, further comprising:
circulating a cleaning fluid into the annulus across the subsurface formation to remove
20 at least a portion of the rock material that has collapsed; and
producing hydrocarbon fluids from the subsurface formation through a network of
created fractures above the collapsed wellbore.

10. The method of claim 8, further comprising:
25 further inducing the wellbore to collapse by reducing fluid pressure within the
deviated portion of the wellbore.

11. The method of claim 10, wherein the fluid pressure is reduced to below initial
reservoir pressure.

30

12. The method of claim 10, wherein reducing fluid pressure comprises circulating a
collapsing fluid into the deviated portion of the wellbore, the collapsing fluid having a
density that is less than a density of the first fluid.

13. The method of claim 12, wherein the collapsing fluid comprises a gas or a light hydrocarbon fluid.

5 14. The method of claim 1, wherein the first fluid is an organic solvent.

15. The method of claim 1, where the first fluid comprises a detergent which comprises a quaternary ammonium compound.

10 16. The method of claim 1, wherein the first fluid comprises an acidic fluid which comprises at least 10% by volume hydrochloric acid, acetic acid, or formic acid.

17. The method of claim 1, wherein the first fluid comprises an oxygen-releasing compound which comprises hydrogen peroxide, sodium perborate, sodium percarbonate,
15 sodium persulfate, tetrasodium pyrophosphate, or urea peroxide.

18. The method of claim 1, wherein the first fluid comprises a bleaching compound which comprises sodium hypochlorite or calcium hypochlorite.

20 19. The method of claim 8, further comprising:
further inducing the wellbore to collapse by changing the temperature of the formation immediately adjacent to the bottom of the wellbore, and
wherein changing the temperature of the formation comprises increasing the temperature of the formation immediately adjacent to the bottom of the wellbore by at least
25 100° F.

20. The method of claim 1, further comprising:
installing nozzles proximate the end of the working string; and
jetting the first fluid against the rock matrix in order to further break off rock material
30 from the bottom portion of the subsurface formation and enlarge the annulus.

21. The method of claim 1, further comprising:
oscillating the first fluid in order to further break off rock material from the bottom portion of the subsurface formation and enlarge the annulus.

22. The method of claim 21, wherein oscillating the first fluid comprises reciprocating a downhole plunger, cyclically changing downhole fluid pressure using a pump at a surface, or generating ultrasonic frequencies downhole in excess of 10 kHz.

5

23. The method of claim 1, wherein:

the subsurface formation is a rock matrix comprising shale;

the wellbore is completed substantially horizontally along the bottom portion of the subsurface formation; and

10 a volume of collapsed shale is at least about 100 cubic meters.

24. A method for improving hydrocarbon production from a subsurface formation, comprising:

15 drilling a wellbore into a subsurface formation, the subsurface formation comprising shale, and the subsurface formation having an initial permeability that is less than about 10 millidarcies;

continuing to drill the wellbore proximate a bottom portion of the subsurface formation such that the wellbore extends substantially horizontally through the bottom portion of the subsurface formation;

20 running a working string into the wellbore, the working string extending into the bottom portion of the subsurface formation, and forming an annulus between the working string and the surrounding formation;

selecting a first fluid to produce via chemical interaction (i) a swelling of the shale, (ii) a disaggregation of the shale, (iii) a dissolution of particles within the shale, or (iv) combinations thereof;

25 circulating the first fluid into the annulus across the subsurface formation and back up a bore of the working string in order to break off rock material from the bottom portion of the subsurface formation and enlarge the annulus;

30 reducing pressure in the bottom portion of the wellbore in order to induce at least a portion of the wellbore to substantially collapse;

producing hydrocarbon gasses from the subsurface formation.

25. The method of claim 24, wherein reducing pressure in the wellbore comprises circulating a collapsing fluid into the deviated portion of the wellbore, the collapsing fluid having a density that is less than a density of the first fluid.

5 26. The method of claim 25, wherein the collapsing fluid comprises (i) a gas, (ii) a hydrocarbon fluid, (iii) water having a salt content less than about 1% by mass, or (iv) an acidic fluid.

27. The method of claim 24, further comprising:

10 selecting a cleaning fluid for carrying rock material from the subsurface formation that has broken off; and

circulating the cleaning fluid into the annulus across the subsurface formation to remove at least a portion of the rock material that has broken off.

15 28. The method of claim 27, wherein the cleaning fluid contains a viscosifier to facilitate the transport of rock material up the bore of the working string during reverse-circulating.

29. The method of claim 27, wherein the cleaning fluid is a reactive fluid that has substantially the same composition as the first fluid.

20

30. The method of claim 27, further comprising:

withdrawing the working string incrementally while continuing to circulate the cleaning fluid.

25 31. The method of claim 28, further comprising:

changing a temperature of the cleaning fluid before circulating in order to change a temperature of the formation immediately adjacent to a bottom portion of the wellbore.

32. The method of claim 27, further comprising:

30 again circulating the first fluid into the annulus across the subsurface formation and back up a bore of the working string in order to break off additional rock material from the bottom portion of the subsurface formation and further enlarge the annulus

33. The method of claim 24, wherein circulating the first fluid comprises reverse-circulating the first fluid.

34. A method for improving hydrocarbon production from a subsurface formation comprising a rock matrix, the method comprising:

drilling a wellbore into the subsurface formation using a drill string and connected drill bit;

selecting a first fluid which chemically interacts with the rock matrix adjacent to the wellbore to weaken the rock matrix;

flowing the first fluid into the wellbore and across the subsurface formation such that the first fluid contacts the rock matrix along the subsurface formation adjacent to the wellbore; and

withdrawing the drill string from the subsurface formation.

35. The method of claim 34, wherein the first fluid is flowed down an annulus formed between the drill string and the surrounding subsurface formation and up the drill string to a surface before withdrawing the drill string from the subsurface formation.

36. The method of claim 34, further comprising:

rotating the drill string and a connected rock grinding device back along the subsurface formation to grind out at least a portion of broken rock material.

37. The method of claim 36, wherein the first fluid chemically interacts with the rock matrix to cause a swelling of the rock matrix, dissolution of inorganic particles within the rock matrix, or dissolution of organic binders within the rock matrix.

38. The method of claim 36, further comprising:

circulating a cleaning fluid through the drill string while rotating the drill string and connected rock grinding device back along the subsurface formation, wherein the cleaning fluid has substantially the same composition as the first fluid, and wherein the cleaning fluid is circulated down the annulus between the drill string and the surrounding subsurface formation, and back up a bore of the drill string.

39. The method of claim 34, further comprising:

circulating a collapsing fluid into the such that the collapsing fluid further induces formation collapse;

rotating the drill string and a connected rock grinding device back along the subsurface formation to grind out at least a portion of newly broken rock material;

5 circulating a cleaning fluid through the drill string while rotating the drill string and connected rock grinding device back along the subsurface formation to at least partially clean out the wellbore; and

withdrawing the working string incrementally while continuing to circulate the cleaning fluid.

10

40. The method of claim 39, further comprising:

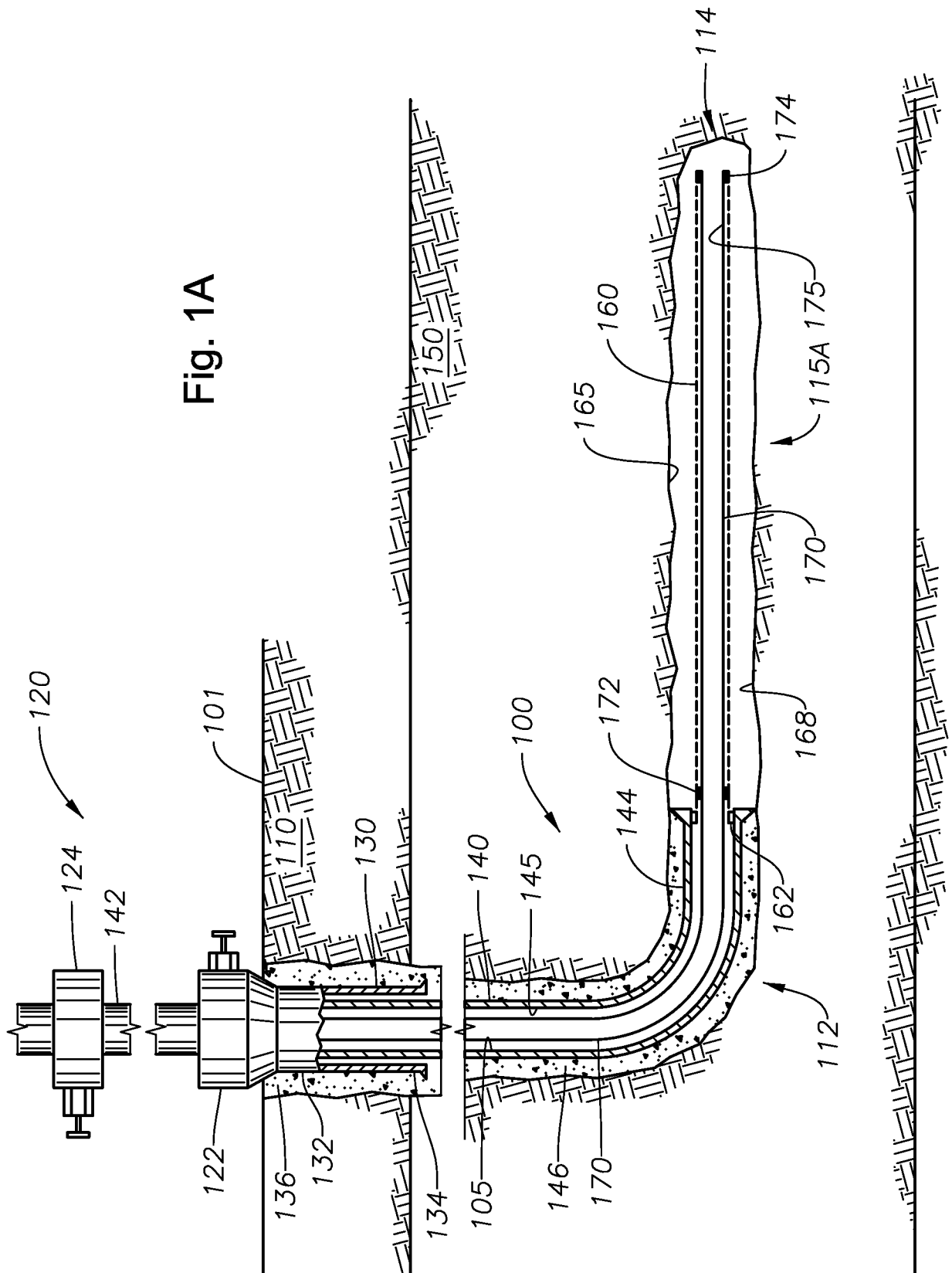
placing a collapsing fluid into the wellbore such that the collapsing fluid further induces formation collapse; and

producing hydrocarbon fluids from the subsurface formation.

15

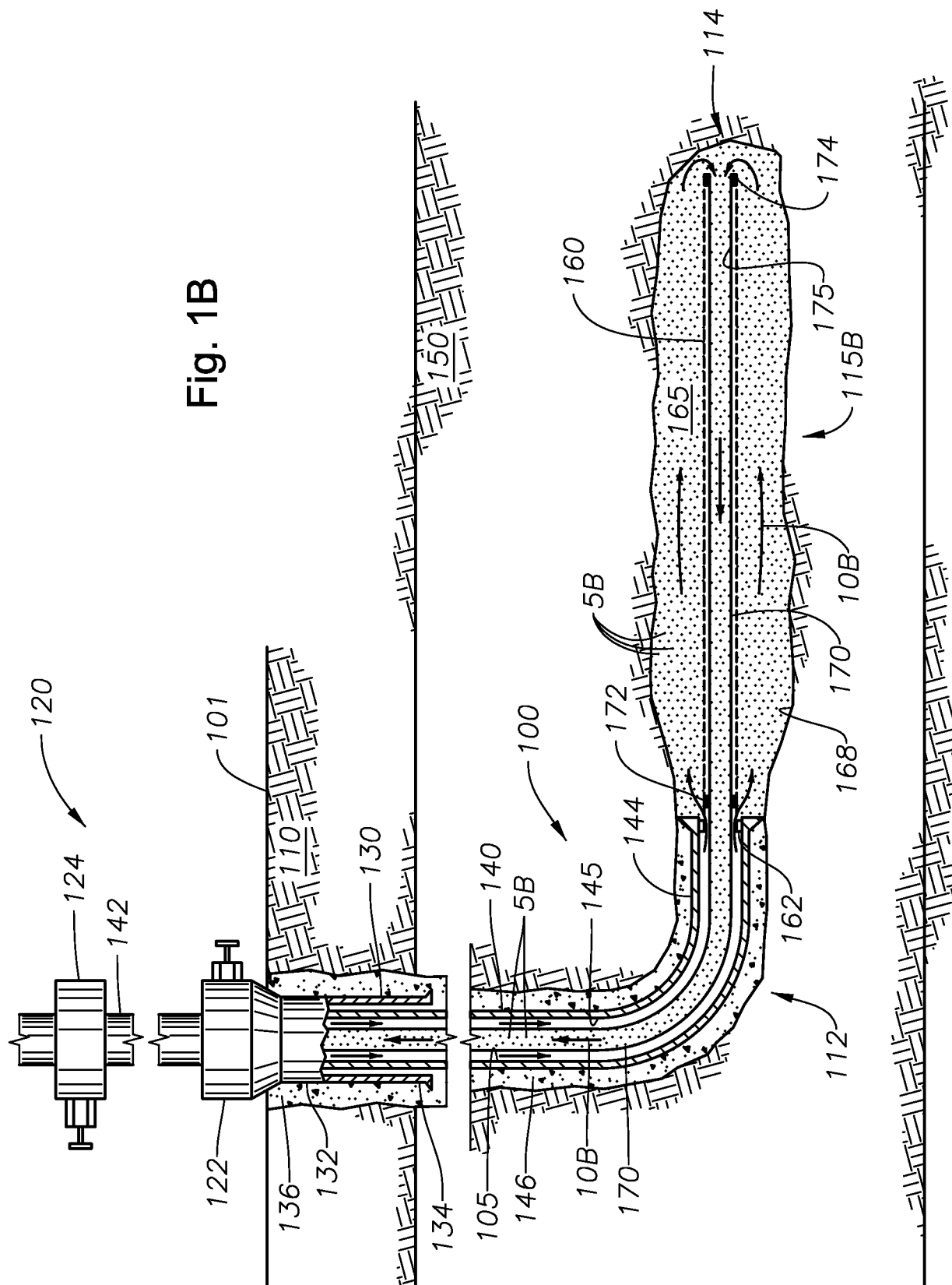
1/14

Fig. 1A



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Fig. 1B



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Fig. 1C

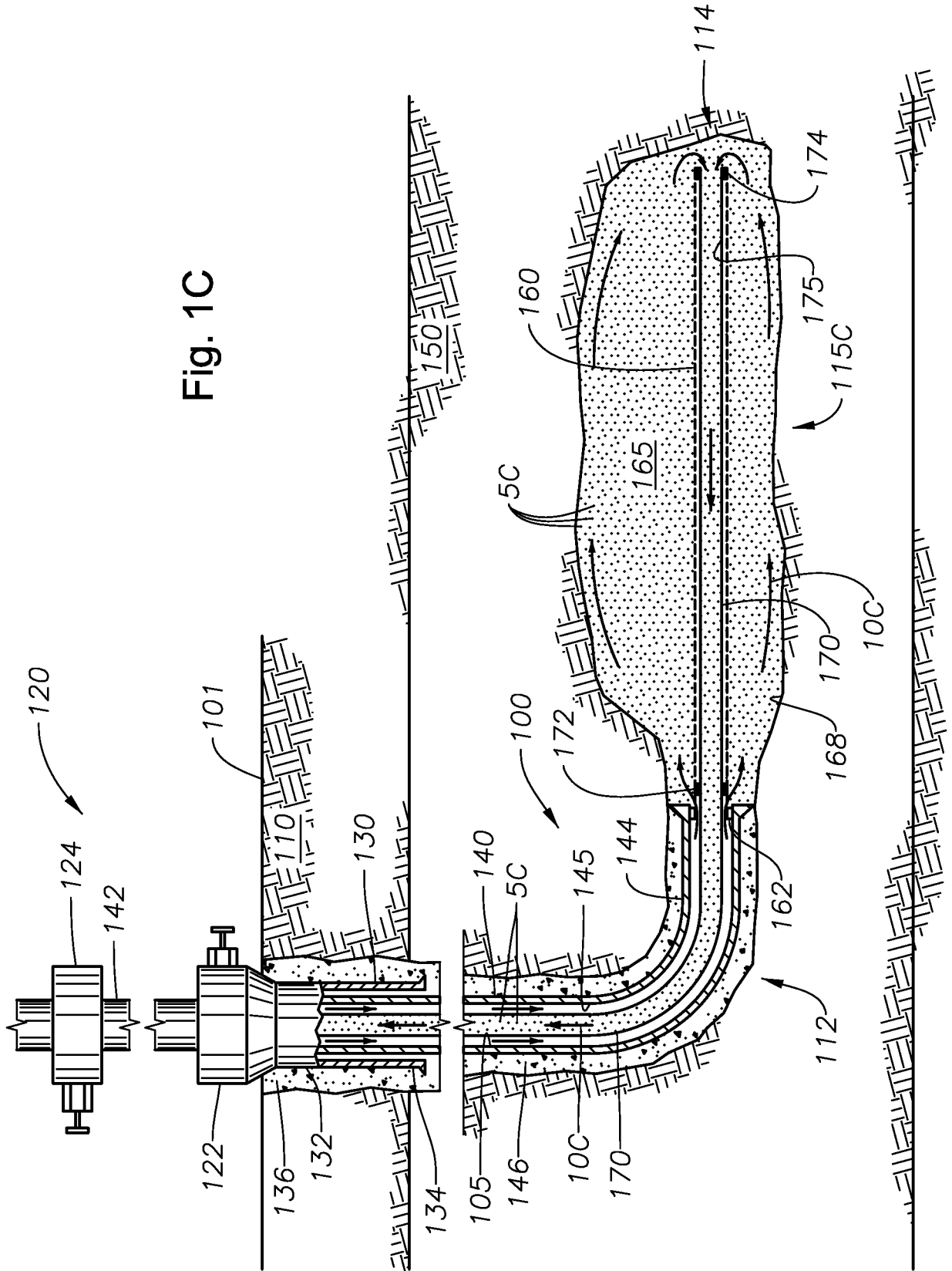
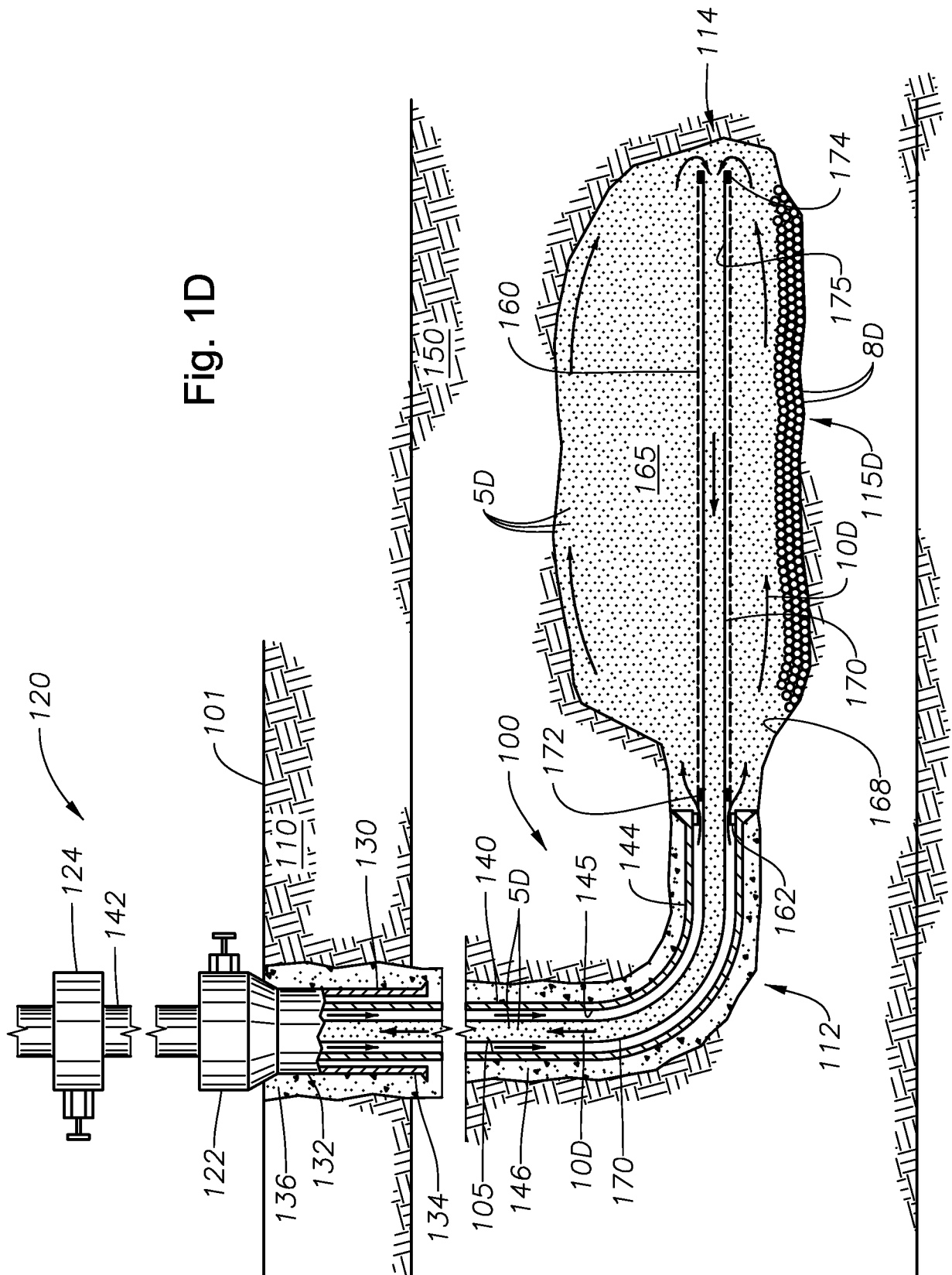
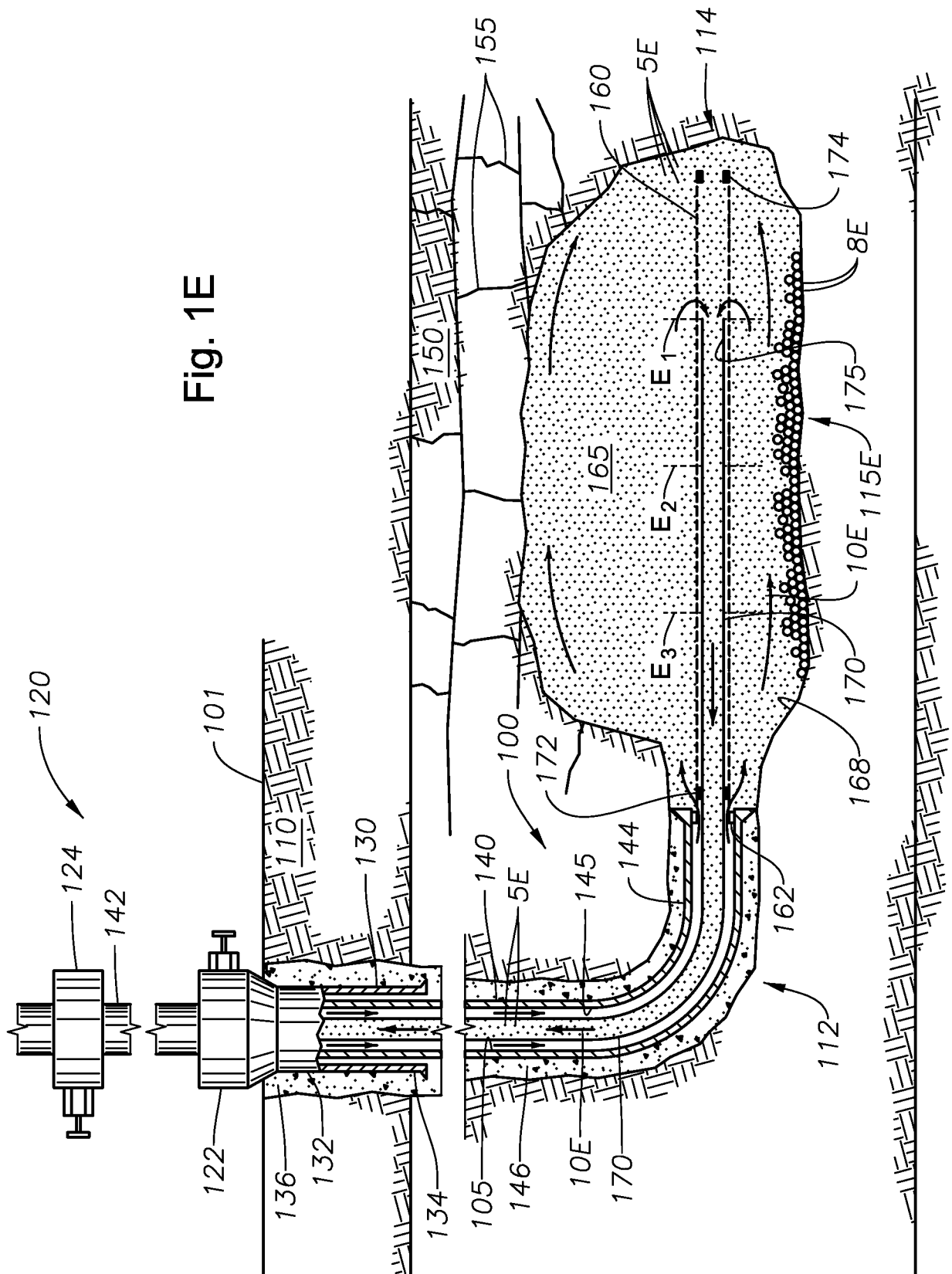


Fig. 1D



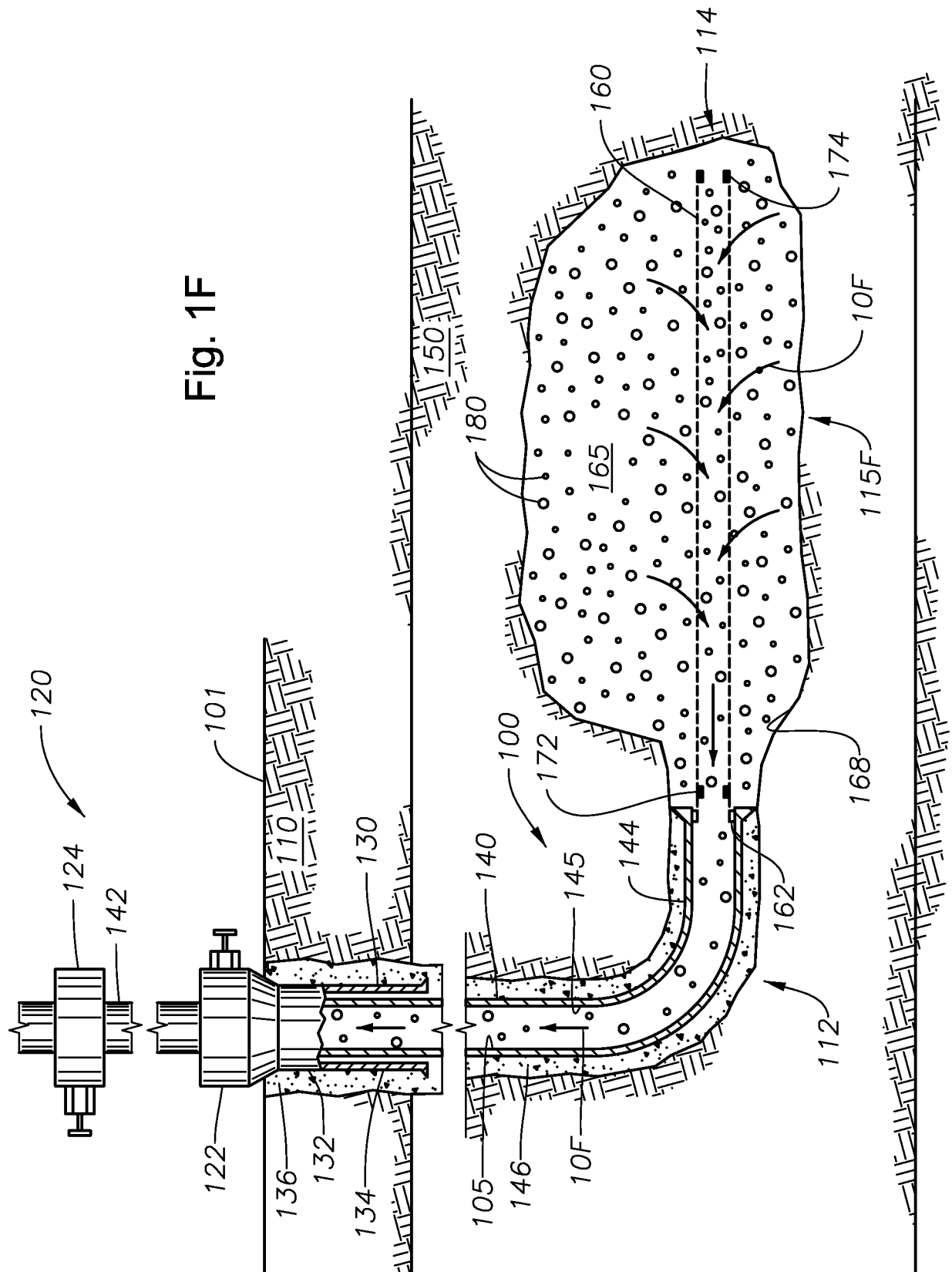
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Fig. 1E



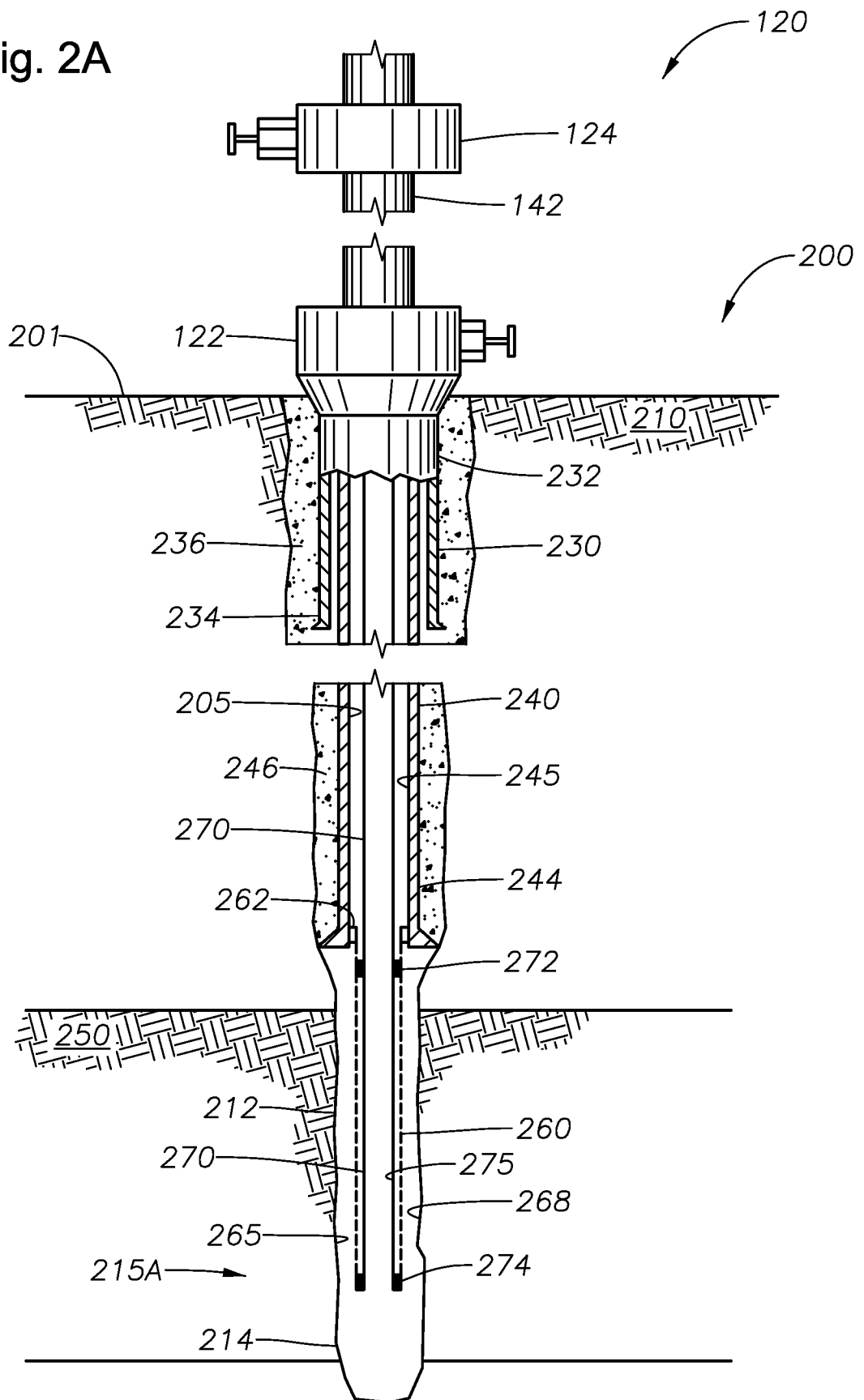
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Fig. 1F



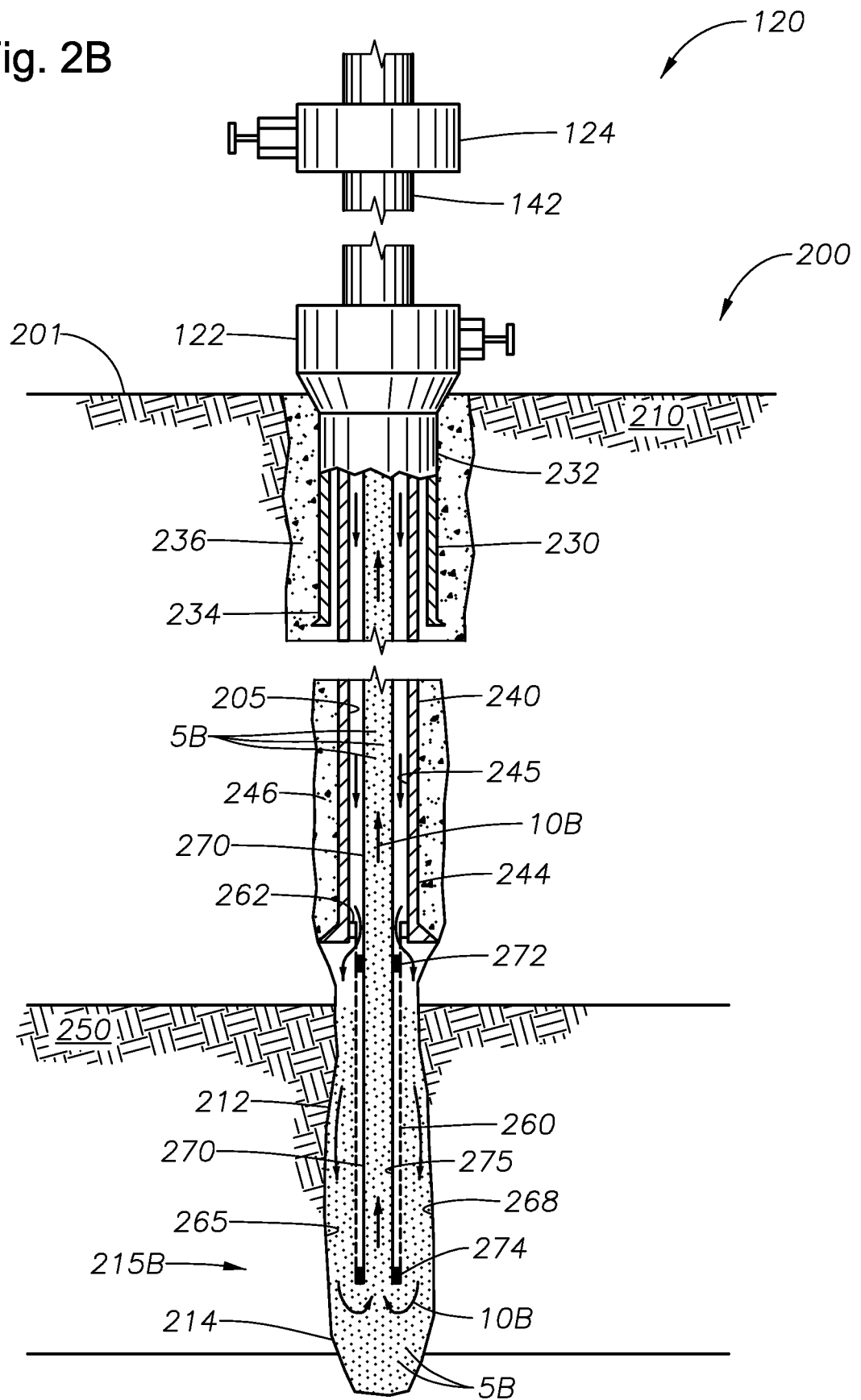
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Fig. 2A



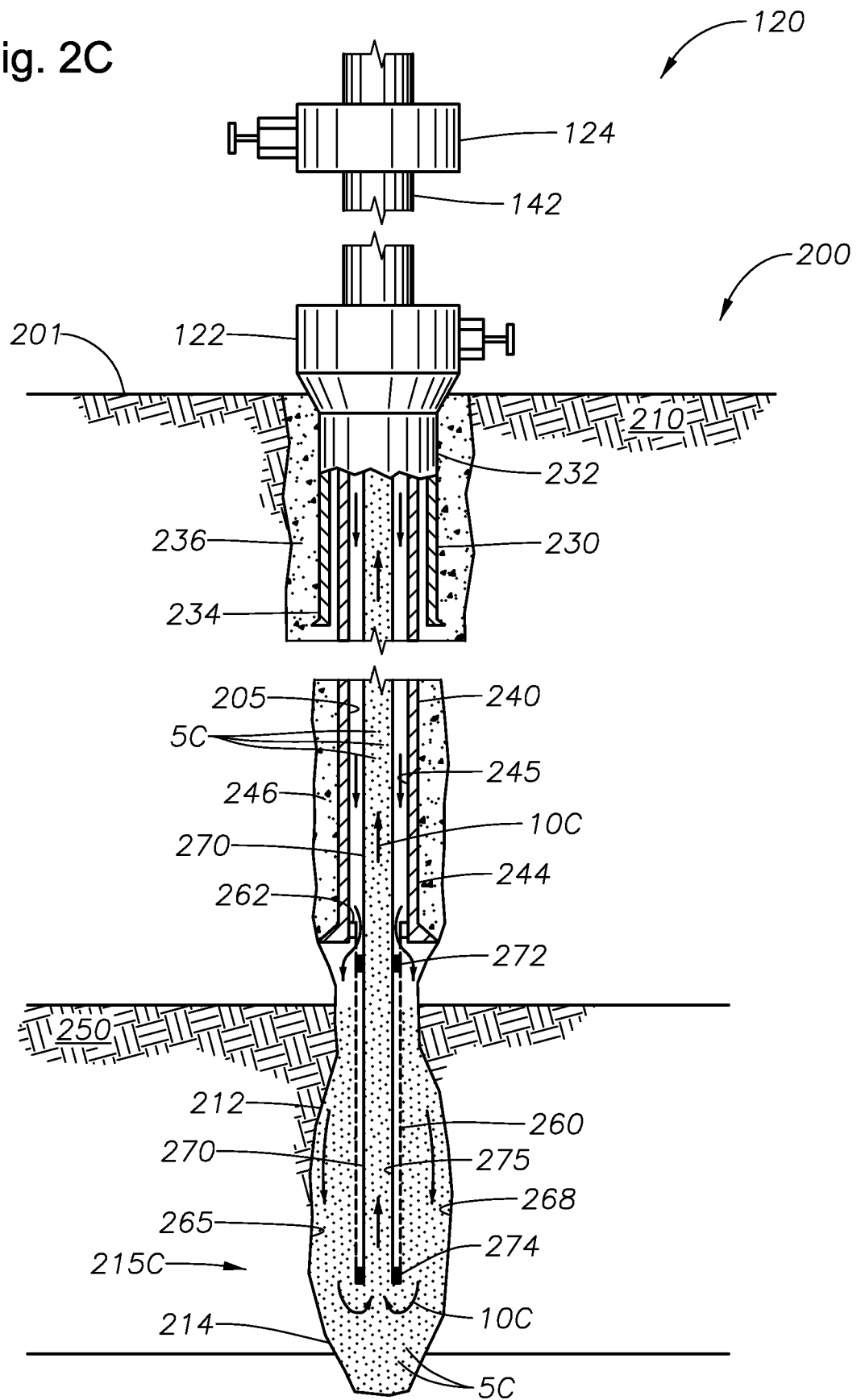
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Fig. 2B



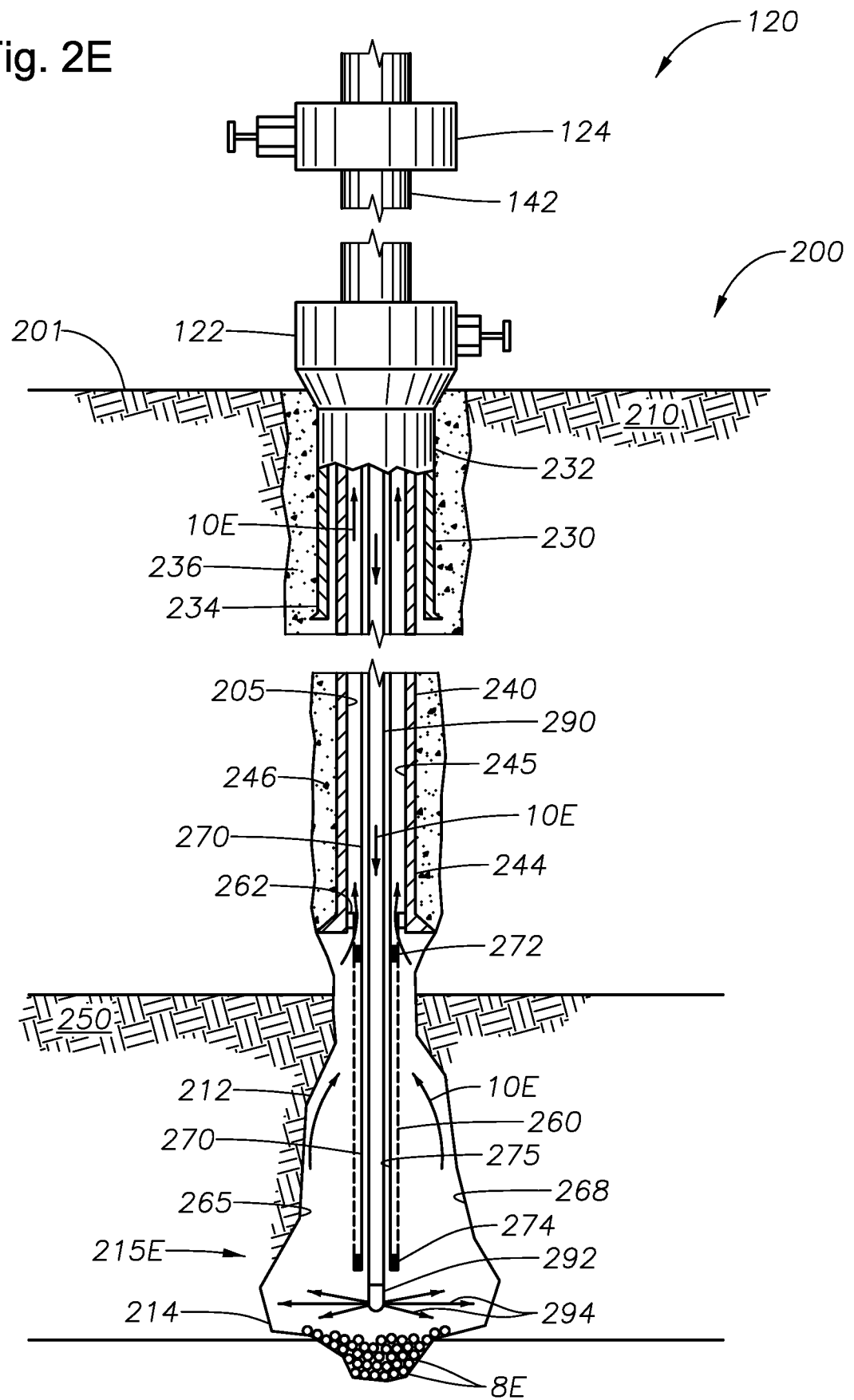
9/14

Fig. 2C



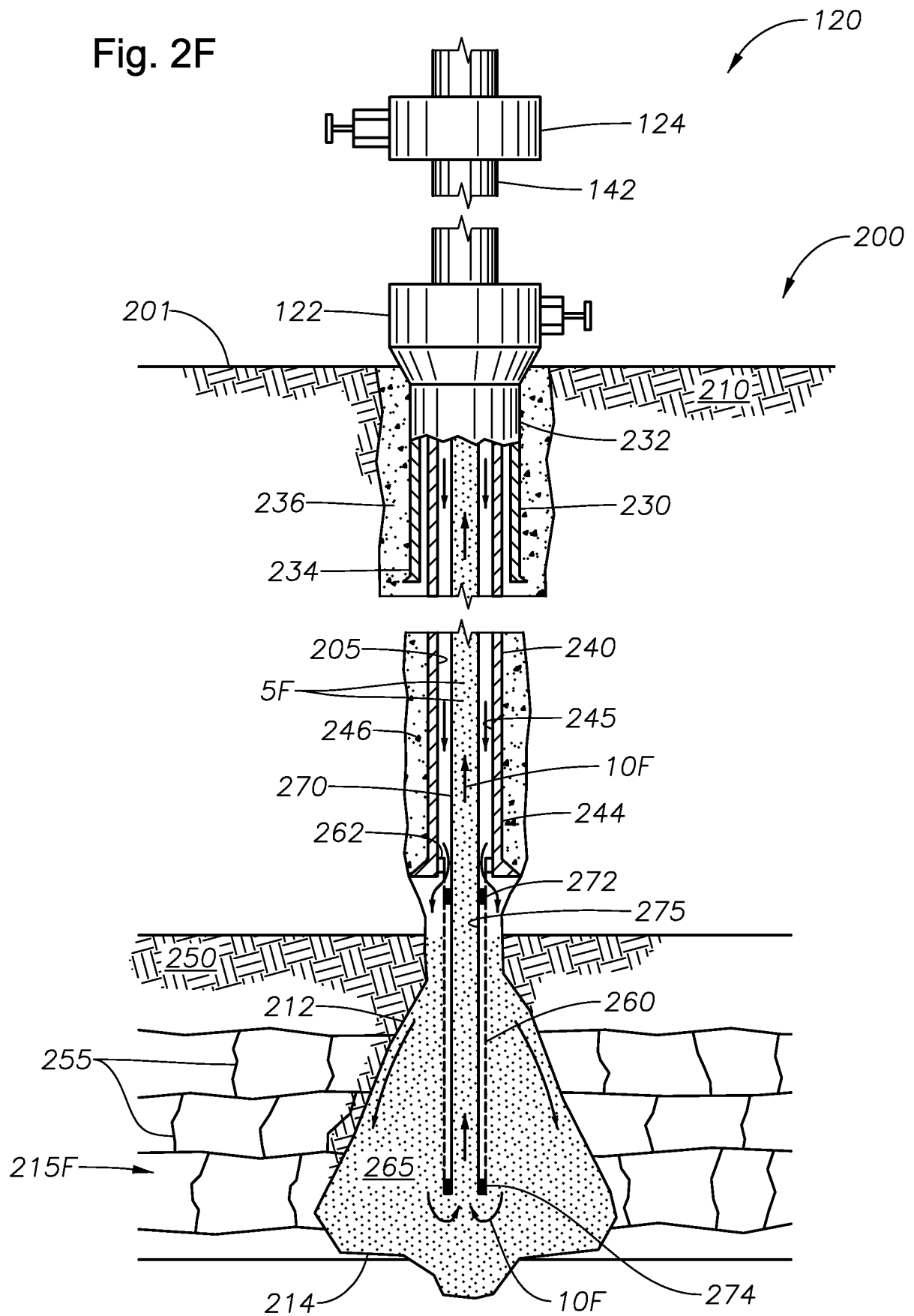
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Fig. 2E



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Fig. 2F



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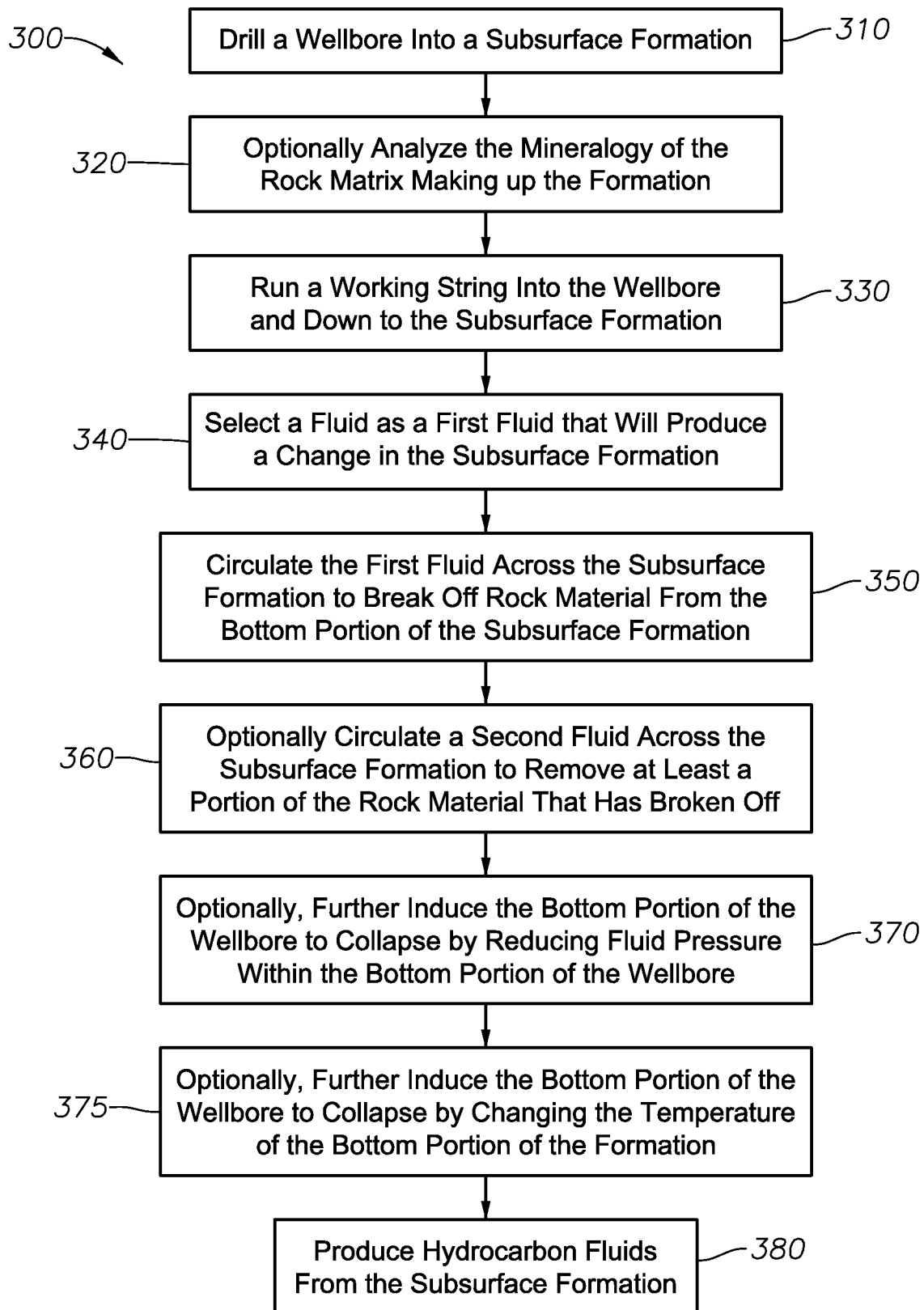


Fig. 3

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 11/39146

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - E21B 43/27 (2011.01)

USPC - 166/272.2

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)

USPC: 166/272.2

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

USPC: 166/271, 272.1, 272.2, 272.7, 302, 303, 308, 308.2, 311, 312; 175/62, 64, 65; 507/103, 140 (text search - see terms below)

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

PubWEST(USPT,PGPB,EPAB,JPAB); Google Search Terms Used: fracture, collapse, remove, rock, debris, enlarge, annulus, increase, shale, disaggregation, swelling, dissolution, millidarcies, cleaning, fluid, pre-perforated, viscosifier, reverse, circulation, wellbore, analyze, mineralogy, chemical, working string, ultrasonic, select, determine, drill,

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X -- Y	US 2010/0089574 A1 (WIDEMAN et al.) 15 April 2010 (15.04.2010), entire document especially Abstract; Fig 4A, 4B; para [0008], [0010]-[0012], [0027], [0061], [0065], [0073]-[0074], [0076], [0079], [0082], [0084], [0112]-[0113], [0125], [0134], [0139]-[0141], [0149], [0150], [0152]-[0154], [0167], [0175]	1-3, 5, 8, 14, 17-20, 34-38 ----- 4, 6-7, 9-13, 15-16, 21-33, 39-40
Y	US 2006/0201715 A1 (SEAMS et al.) 14 September 2006 (14.09.2006), entire document especially Abstract; Fig 1, 3-5; para [0005]-[0007], [0027], [0043]-[0051], [0053], [0062]	9-13, 23-33
Y	US 7,147,067 B2 (GETZLAF et al.) 12 December 2006 (12.12.2006), col 4, ln 32-46	4
Y	US 6,755,249 B2 (ROBISON et al.) 29 June 2004 (29.06.2004), col 5, ln 56-67; col 6, ln 31-46	6
Y	US 3,284,281 A (THOMAS et al.) 08 November 1966 (08.11.1966), col 2, ln 26-34 and ln 51-56	7
Y	US 7,290,615 B2 (CHRISTANTI et al.) 06 November 2007 (06.11.2007), col 2, ln 41-56	15-16
Y	US 4,071,097 A (FULOP et al.) 31 January 1978 (31.01.1978), Abstract; col 2, ln 40-52; col 5, ln 24-51	21-22
Y	US 5,964,289 A (HILL) 12 October 1999 (12.10.1999), col 3, ln 8-22; col 4, ln 1-9; col 12, ln 1-4	12-13, 23, 25-26, 39-40
Y	US 2006/0086507 A1 (SURJAATMADJA et al.) 27 April 2006 (27.04.2006), para [0009]	30, 39-40
Y	US 2008/0135226 A1 (LEWIS et al.) 12 June 2008 (12.06.2008), para [0004], [0011]	30, 39-40

☒ Further documents are listed in the continuation of Box C.

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search

04 October 2011 (04.10.2011)

Date of mailing of the international search report

19 OCT 2011

Name and mailing address of the ISA/US

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PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 11/39146

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 3,951,456 A (RIDLEY) 20 April 1976 (20.04.1976), entire document especially col 1, ln 61-col 2, ln 9; col 6, ln 67-col 7, ln 3	23
A	US 2008/0017417 A1 (TIBBITS) 24 January 2008 (24.01.2008), entire document especially para [0061]	30
A	US 2003/0121701 A1 (POLIZZOTTI et al.) 03 July 2003 (03.07.2003), entire document especially the Abstract; Fig 2	1-40
A	Advances in Unconventional Gas, Solutions to meet growing gas demand worldwide. Halliburton, [online], Houston, TX, Hart Energy Publishing, January 2007 (01.2007), [retrieved on 01 October 2011 (01.10.2011)]. Retrieved from the Internet:<URL: http://www.halliburton.com/public/pe/contents/Papers_and_Articles/web/Q_through_Z/UnconventionalGas_H05270.pdf > pg 7, 21	1-40