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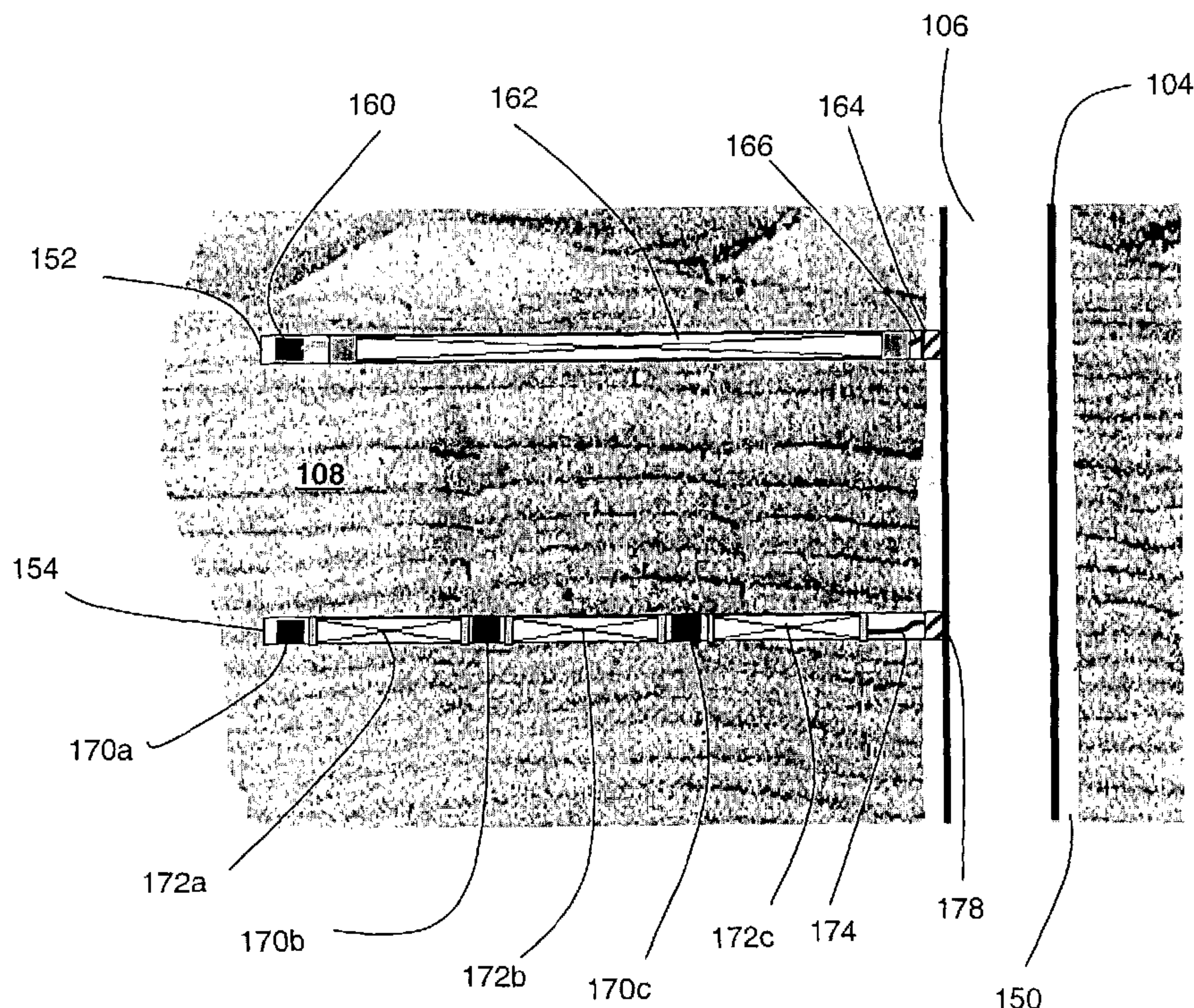
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MICROFORAGES

(54) Title: SYSTEM AND METHOD FOR INSTALLATION AND USE OF DEVICES IN MICROBOREHOLES



(57) Abrégé/Abstract:

Making measurements with a main borehole and a microborehole extending from the main boehole into the formation, is performed with sensing devices positioned to measure at zones located in the microborehole. One or more packers can be installed in the microborehole to hydraulically isolate the measurement zones from each other and/or main borehole. In a microborehole fluid samples can be taken, fluid tracers be injected and various sensors including geophones can be incorporated.



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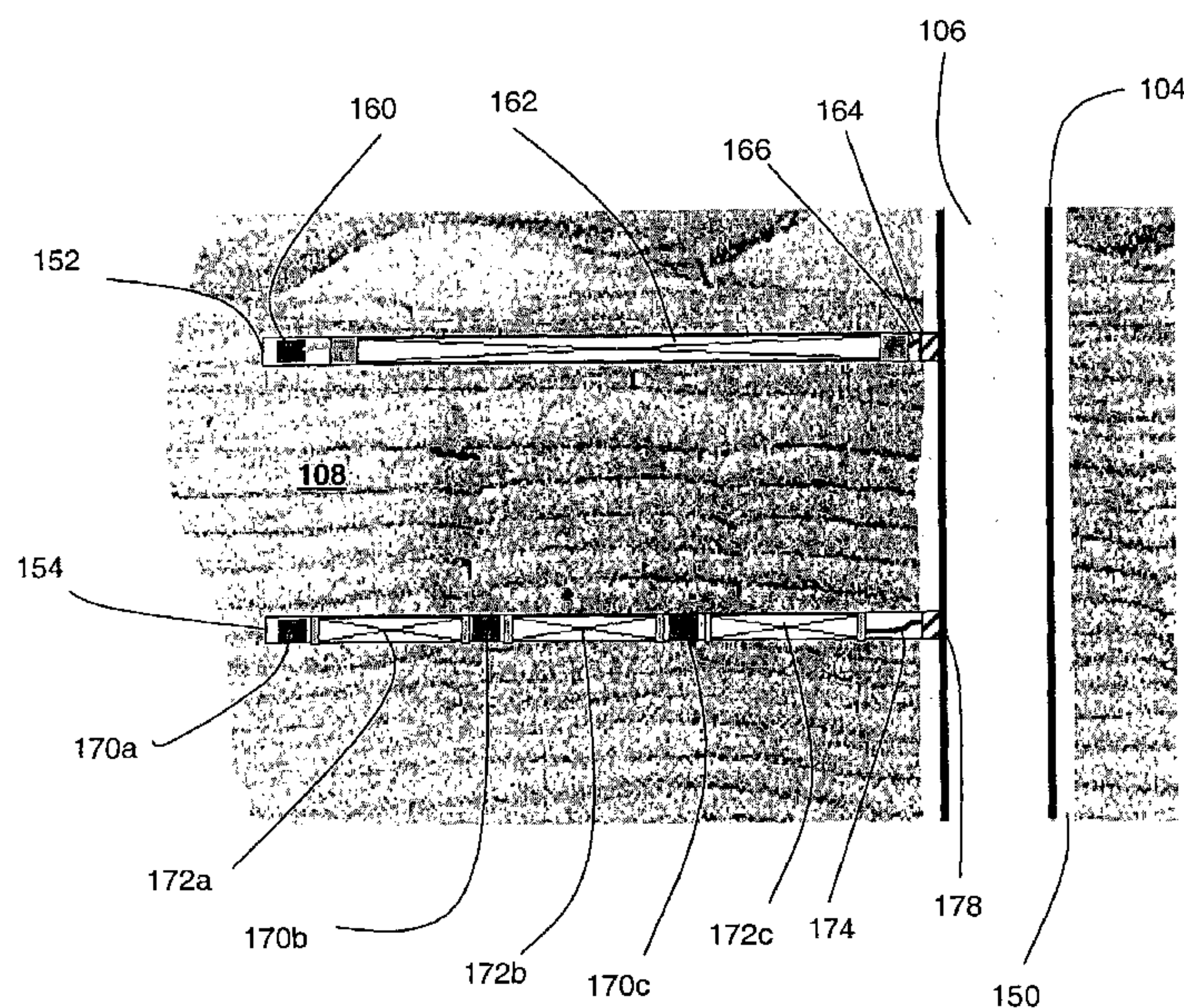
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(54) Title: SYSTEM AND METHOD FOR INSTALLATION AND USE OF DEVICES IN MICROBOREHOLES



(57) Abstract: Making measurements with a main borehole and a microborehole extending from the main boehole into the formation, is performed with sensing devices positioned to measure at zones located in the microborehole. One or more packers can be installed in the microborehole to hydraulically isolate the measurement zones from each other and/or main borehole. In a micro-borehole fluid samples can be taken, fluid tracers be injected and various sensors including geophones can be incorporated.

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System and Method for Installation and Use of Devices in
Microboreholes

FIELD OF THE INVENTION:

5 The present invention relates to the field of
boreholes oilfield services applications. In particular,
the invention relates to methods and systems which are
used in microboreholes or microlaterals opened from a
main wellbore.

10 BACKGROUND OF THE INVENTION:

Drilling secondary holes from a main borehole
is an established technology, for example in creating
sidetracks and multilateral wells for formation
15 evaluation or production enhancement. These
multilaterals have diameters comparable to the parent
borehole. Because of the stiffness of the assembly used
to drill them, they take off from the parent hole at a
shallow angle, leaving a large elliptical opening at the
20 junction. If the junction needs to be sealed, this
requires a considerable investment in a mechanical
junction of some kind, over and above the investment of
time and money required to drill the multilateral hole in
the first place.

25 Because of this, a multilateral well is
typically drilled for production enhancement or control
of some kind, when access to a part of the reservoir far
from the main borehole is needed. The technology for
accessing the reservoir close to the main borehole is
30 also very well established, namely shaped charge
perforators. These open channels into the formation,
through the casing and cement, to allow the flow of

hydrocarbons into the well or treatment fluids into the formation. The holes in the casing created by shaped charges are not smoothly shaped, but are ragged or rough; this makes them difficult to seal, should this be
5 required. The holes created in the rock are also not smooth, clean or uniformly shaped; they are tapered, have a rough wall, and contain debris, and their dimensions depend on rock strength and many other factors.

Due in large part to the aforesaid
10 characteristics, multilateral holes and shaped charge holes are not suitable for a number of uses which would benefit from the access to the rock formation surrounding the main well bore.

15

SUMMARY OF THE INVENTION:

Thus, it is an object of the present invention to provide a system and method for installing and using devices in microboreholes.

20

According to the invention a system is provided for making measurements associated with a rock formation comprising a main borehole, a microborehole extending from the main borehole into the rock formation, a sensing device positioned and arranged to make a measurement at a
25 measurement zone being located in the microborehole away from the main borehole by a distance of at least the diameter of the main borehole, and a packer installed in the microborehole dimensioned and arranged to hydraulically isolate the measurement zone from
30 conditions present in other parts of the microborehole and/or main borehole.

According to various embodiments of the invention, the sensing device can be one or more pressure sensors, including sensors for pore pressure in shale formations, a water or gas detector, an electrical sensor
5 to detect electroseismic activity, a temperature sensor, or a chemical sensor.

According to another embodiment of the invention a system is provided for making measurements associated with a rock formation comprising a main
10 borehole, a microborehole extending from the main borehole into the rock formation, and a sensing device at least part of which is positioned in the microborehole away from the main borehole by a distance at least the diameter of the main borehole.

15 According to various embodiments, the sensing device can be a tilt meter, a geophone, a magnetometer, or a sensor adapted to detect compaction of the rock formation.

According to various other embodiments of the
20 invention, multiple measurements can be made along the length of the microborehole using the sensing device. This can be accomplished using multiple sensors placed at different locations in the microborehole, or by moving the sensing device along the microborehole while making
25 measurements. The sensing device can be a resistivity meter or an ultrasonic imaging device.

According to another embodiment of the invention a sampling device is positioned and arranged to take a fluid sample at a sampling zone being located in
30 the microborehole away from the main borehole by a distance of at least the diameter of the main borehole.

According to another embodiment of the invention an injection device is positioned and arranged to inject a tracer at an injection zone being located in the microborehole away from the main borehole by a
5 distance of at least the diameter of the main borehole.

The invention is also embodied in a method of installing a sensor in a microborehole, and a method for making measurements associated with a rock formation in a microborehole.

10 As used herein the term microlaterals and microboreholes means any holes bored from a main borehole having a diameter substantially less than that of the main borehole and a length longer than the diameter of the main borehole. Typically microlateral and
15 microboreholes are approximately or nearly perpendicular to the main borehole, around 15-50 mm diameter and 2 - 3 meters long.

BRIEF DESCRIPTION OF THE DRAWINGS:

20

Figure 1 shows a schematic of tool suitable for use with the present invention;

Figure 2 shows steps for making use of microboreholes according to several preferred embodiments
25 of the invention;

Figure 3 shows a schematic diagram of two microboreholes extending from a main borehole into a rock formation, according to the invention; and

Figure 4 also shows devices installed in
30 microboreholes extending from a horizontal portion of the main wellbore, according to the invention.

DETAILED DESCRIPTION OF THE INVENTION:

According to the invention, creating a relatively smooth
5 hole through the casing and formation, with a known size,
allows emplacement of sensors or other devices, followed
by sealing of the hole in the casing to give isolation of
the sensor from the contents of the wellbore. This can
be done by Schlumberger's Cased Hole Dynamics Tester,
10 mounted on the MDT platform on wireline. See U.S. Patent
No. 5,692,565, hereby incorporated herein by reference;
"Wireline-Conveyed Through-Casing Formation Tester
Preserves Casing Integrity" by Burgess et al., Society of
Petroleum Engineers, SPE 72371, hereby incorporated
15 herein by reference, and Cased Hole Dynamics Tester
Brochure(http://www.connect.slb.com/Hub/brochure/brochure.cfm?printable=1&b=connect/formation_evaluation/Cased_Hole_Dynamics_Tester&id=id670409&bList=brochure01,brochure02,brochure03,brochure04,brochure05&n=1) hereby incorporated
20 herein by reference. With this type of arrangement, the
maximum depth of the hole is currently limited to around
150 mm. This depth allows fluid sampling or a valid
measurement of formation fluid pressure in a permeable
formation from a cased well. However, some types of
25 measurements in a hole of this depth would be compromised
by the proximity of the main borehole. For example,
formation temperature will be strongly influenced by the
history of fluid circulation in the main borehole; and
stresses and mechanical properties are perturbed by the
30 stress concentration around the main borehole.

According to the invention, in order to make
measurements unperturbed by the presence of the main

borehole, sensors should be placed much further away from it; ideally between 5 and 10 wellbore diameters. Small holes, 2 to 3 meters long and 2 to 3 centimeters in diameter, perpendicular to the main borehole, allow the
5 placement of many different types of devices, for sensing, injecting, generating signals, etc., as well as other functions.

A technology such as that provided by the tool known as Penedrill, from Penetrators Canada, in Red Deer,
10 Alberta (www.penedrill.com) is preferred according to a preferred embodiment of the invention. The penedrill system is described in US Patent No. 6,167,968, hereby incorporated herein by reference. The Penedrill tool is preferably mounted on jointed or coiled tubing, and
15 drills a hole through the casing with a drill bit designed for metal, then uses an internal shuttle to move a rock drilling assembly into place. Such an arrangement can then drill up to 2 meters into the formation at right angles to the main borehole. The drilling and assembly
20 changeover are preferably controlled and powered hydraulically from the surface, and a drilling operation may take between 3 and 20 minutes. Around ten holes can be drilled in a single trip.

Figure 1 shows a schematic of a tool suitable
25 for use with the present invention, such as the Penedrill tool. Tool 102 is shown deployed in a wellbore in rock formation 108 and cased with casing 104.

The tool 102 according a preferred embodiment of the invention is approximately 30 feet long and
30 approximately 4" outer diameter. With such dimensions, the tool would be suitable where the main well bore, or casing, is between 4.5" and 7" in diameter. The tool is

preferably modified to larger diameter for larger casing or hole sizes.

The tool 102 is supported by tubing 110. Tubing 110 can be either jointed or coiled tubing.

5 Anchor 114 is used to fix the position of the tool during the microborehole drilling operation. Filter 116 is provided for protection of the tool from unwanted particulate matter in the hydraulic line.

Control section 116 is a hydraulically actuated
10 valve assembly allowing actuation of the tools by the operator at the surface. Fluid is returned to the surface via tubing/casing annulus 106. The maximum tubing pressure is preferably about 26Mpa (3770 psi).

Motor section 120 and drill section 122 develop
15 the rotation, extension and retraction used for drilling the microborehole. The drill bit within drill section 122 is preferably a diamond rock bit and drills microboreholes of about 17 mm in diameter.

Mill section 124 mills a hole in the production
20 casing (if present) and allows the drill bit to access the rock formation. A shift sequence is preferably performed hydraulically. For a 17 mm microborehole the casing hole window should be about 26 mm. Mill section 124 includes the tool deployment channel 126 through
25 which the drilling tool and other equipment and devices are inserted into the rock formation.

Another type of device which could also be used for drilling through the casing for use with some embodiments of the present invention is described in US
30 Patent 6,378,629, hereby incorporated herein by reference. The technique is disclosed by Saturn Machine and Welding Co. of Kentucky.

Los Alamos National Labs have disclosed a technique for acoustic sensor or source placement in small diameter boreholes drilled directly from the surface. See, Albright, J.N. and Dreesen, D.S.,
5 "Microhole technology lowers reservoir exploration, characterization costs", Oil and Gas Journal special issue, Jan. 10, 2000, p. 39; "Models support potential for drilling deep microholes", Oil and Gas Journal, Jan. 17, 2000, p. 56, both hereby incorporated herein by
10 reference.

Figure 2 shows steps for making use of microboreholes according to several preferred embodiments of the invention. As shown in Figure 2, in step 210, the main borehole is drilled and cased using conventional
15 technology. In step 212 a specialized tool for drilling microboreholes is run into the well. For example a tool such as the Penedrill tool can be used in this step to drill one or more microlaterals. The tool is preferably run as a stand-alone tool on the end of coiled or jointed
20 tubing, however the tool could also be provided as part of the main bottom hole assembly and performed while-drilling. If a while-drilling arrangement was used, the main drillstring would be stationary for some time during steps 212.

25 In step 214 packages of devices are inserted into the microlaterals, depending upon the specific desired application (e.g. sensing, pumping, signal generation).

In step 216 the hole is terminated at the
30 casing, preferably using a metal-to-metal plug with some form of data output device. The plug is preferably such

as that used with Schlumberger's Cased Hole Drilling Tool. See, SPE 72371, incorporated by reference above.

In step 218 the devices installed in the microlaterals in step 214 are interrogated or addressed
5 using suitable downhole equipment. The equipment used for the interrogation and/or addressing is on the same toolstring, or another toolstring. Interrogation systems that could be used for this step include that disclosed in U.S. Patent No. 6,234,257, hereby incorporated herein
10 by reference.

Advantageously, the sequence of operations described in Figure 2 allows permanent installation of devices, in good contact with the formation and situated away from the perturbing influence of the main borehole.

15 Figure 3 shows a schematic diagram of two microboreholes 152 and 154 extending from a main borehole 106 into rock formation 108. Main borehole 106 is cased with casing 104 and the annular space between rock formation 108 and casing 104 is filled with cement 150.
20 The microborehole 152 contains a pressure sensor 160 at the far end, and a packer 162 that seals the remainder of the microborehole. The configuration of hole 152 is suitable, for example, for measuring pore pressure in extremely impermeable formations. The microborehole 154
25 contains three pressure sensors 170a, 170b and 170c isolated by packers 172a, 172b and 172c. This configuration of microborehole 154 would be suitable, for example, for measuring radial pressure gradient in a permeable formation.

30 Metal to metal seals 164 and 178 are positioned in the openings of casing 104. Seals 164 and 178 serve to protect the cement 150 and the microborehole contents

including the packers, wires, sensors and any other devices from the contents of the main borehole contents. For example, the main borehole might be exposed to harsh chemicals from an acid treatment, and the seals 164 and 178 protect the cement and contents of the microboreholes from the acid. Preferable, seals 164 and 178 are provided with a data readout capability so that the data from the devices in the microboreholes can be read by interrogation systems within the main borehole. For example, electrical connectors or inductive coupling could be provided.

Connection wiring 174 and 166 is provided to electrically connect the devices within the microboreholes with the seals 178 and 164 respectively.

The sensor devices should be of a diameter to both fit within the dimensions of the microborehole, and to allow for insertion around the corner from the main borehole to the microborehole. The packers are preferably dimensioned to fit closely in the microborehole, so that packers do not need to have high expansion ratio. The sensor devices, the packers and any other equipment which is installed in the microlateral should be designed and dimensioned to be stiff enough to push down the microborehole, but flexible enough to turn the corner from the main borehole to the microlateral. The equipment being installed and the tools used to provide the insertion should also be designed to be robust enough to survive abrasion against rock during installation system plus downhole conditions of chemistry, temperature and pressure. The control system is preferably designed and adapted to allow for the inflation of packers, setting of casing plug, etc.

According to a preferred embodiment, the control system, sensors, packers, and any devices needed to installed the sensor and packers in the microborehole are installed from same tool (tool 102 from Figure 1) as does the
5 drilling of the microborehole, so that only one trip is needed to install the devices, and so that the precise position of the hole is not lost. The casing plugs or seals 164 or 178 should be on the end of the package being installed in the microborehole, for same reasons.

10 Figure 4 shows two microboreholes 180 and 182 bored in rock formation 108 from a portion of main borehole 106 that is horizontal. Figure 4 also shows devices installed in the microboreholes that are not used in conjunction with packers. As will be described in
15 more detail below, according to an embodiment of the invention an extensometer 188 is installed in microborehole 180. Electronics package 186 contains electronics used to make the measurement with the extensometer and convert the measurement to digital form.
20 Metal to metal seal or casing plug 184 provides an adequate seal as described with respect to Figure 3. The seal 184 also preferably includes a connector for electrical communication with electronics package 186 and a data read out antenna that allows for data to be read
25 out from interrogation equipment in the main borehole 106. The electronics package 186 also preferably includes a memory on which can be stored the measurements from the extensometer over a period of time at least as long as the interval between interrogations from equipment in the
30 main borehole 106. According to an alternative embodiment, a telemetry cable is provided within 106 to

allow for the measurement data to be transmitted to the surface directly.

Figure 4 also shows an ultrasonic imaging tool 192 being positioned in microborehole 182. As described in more detail below, the ultrasonic imaging tool 192 can be used to characterize fractures, such as fracture 196 in rock formation 108. Also shown in the insertion tool body 190 being extended into microborehole 182 through the tool deployment channel 126 of tool 102.

According to various preferred embodiments of the invention, a number of different devices will now be described which make use of microborehole technology. According to a preferred embodiment formation pressure in shale is measured. Placing a pore pressure sensor in a microborehole in a shale formation at distances of 2-3 meters from the main borehole greatly alleviates many of the problems associated with measurements of shale pore pressure close to the main borehole. Examples of such problems include errors from the stress concentration close to the main borehole (these stress changes cause long-lasting variations in around the main borehole, the local pore pressure of the shale, so any value measured there is not representative of the far-field value); the effects of temperature variations in the flowing fluid in the main borehole (which cause differential borehole, thermal expansions of rock and pore fluid, resulting in pore pressures that are not representative of the far-field value), chemical effects from the drilling fluid, and hydraulic invasion because of pressure differentials. The shale pressure sensor should preferably be small (to be small and have a very low compressibility, to give a short response time); time (the fluid volume needed to

activate the pressure sensor takes a significant time to leak out of the formation); the volume of free space around the sensor must also be small, because the contents of the space must also be pressurized by fluid coming out of the formation. The measurement point is preferably remote from the wellbore (to minimize the above perturbations); and installed for a relatively long period of time (to ensure that it comes to equilibrium). According to this embodiment as shown in Figure 3 the shale pressure sensor is sensor 160 in microborehole 152, shown installed at the far end of a microlateral, isolated from the main wellbore by a packer 162 filling the remainder of the microlateral 152 and the plug in the casing 164. The sensor is preferably as small as possible and close to the end of the microlateral as possible, in order to meet the small volumes outlined above; miniature transducers such as those manufactured by Entran (www.entran.com) or Memscap (www.memscap.com) would be satisfactory, together with a guard-ring mounting to allow the active face of the transducer to be mounted as close to the rock face as possible. Other suitable sensors have been developed for devices such as described in U.S. Patent No. 6,234,257. The Schlumberger Cased Hole Dynamics Tester drills a short hole through the casing, and has a pressure gauge mounted on the drill assembly. This tool is preferably modified so that the pressure sensor is left in the microborehole when the drill is withdrawn or is installed after drilling. Advantageously, this embodiment provides a semi-routine way of measuring formation pressure in shales. The packer preferably fills the borehole immediately behind the transducer, again to minimize the volume, and should

extend as far towards the main wellbore as possible, to inhibit fluid flow from open sections of the microlateral, through the rock around the packer, and into the measurement volume. Suitable small packers are
5 available in the geotechnical and hydrology industries; for example, IPI, RST, Tam, RocTest and GeoPro, all offer packers down to about 30 mm diameter. Making smaller, flexible packers is not difficult, especially as the differential pressure they need to withstand is very low.
10 Existing small highly accurate pressure sensors can be used, such as conventional or MEMS technology (e.g., Entran, Memscap). Other suitable sensors have been developed for devices such as described in U.S. Patent No. 6,234,257. The Schlumberger Cased Hole Dynamics
15 Tester drills a short hole through the casing, and has a pressure gauge mounted on the drill assembly. This tool is preferably modified so that the pressure sensor is left in the microborehole when the drill is withdrawn or is installed after drilling. This small pressure also
20 allows a soft rubber packer to be used, which would help to prevent very small leaks, which would not be a problem for normal packer functions but would be a problem in shale pressure measurements. According to another embodiment, radial pressure gradient is measured. Two or
25 more pressure sensors are installed along a single microlateral, with packers filling the gaps, such as shown in microborehole 154 in Figure 3. During production, the radial pressure gradient can be established, allowing evaluation of skin, non-Darcy
30 effects, condensate or water banking, etc. These measurements advantageously help in improving the interpretation of well testing data. If permeability is

known, radial pressure gradient gives, from Darcy's law, local inflow rate into the well. High-accuracy pressure measurements in radial tunnels in a non-flowing well could help to identify horizontal pressure gradients in a reservoir, and hence observe tilted fluid contacts. The equipment used to install the sensors and the sensors themselves are similar to those used in and described with respect to the previous embodiment.

According to another embodiment seismic sensors, such as geophones or hydrophones are installed in the microborehole for permanent seismic monitoring. Measurements from the geophones can be used for a variety of purposes including active and passive seismic monitoring of reservoir behavior, mapping of hydraulic fracture geometry; and repeat surveys with very constant sensor positioning. The sensors are preferably positioned away from the wellbore which considerably reduces the flow noise that they will measure. According to the invention, sensors can be installed in multiple laterals in opposing directions which provides enough aperture to use arrival time difference to determine source direction (3 laterals, or 2 laterals and a geophone in the main borehole are needed to make this unambiguous). Advantageously, the use of geophones in laterals, and in a main borehole makes a 2D geophone array possible - with a consequent increase in 3D azimuthal resolution. Suitable geophone arrays include the 0.5 inch geophone array and 0.875 inch accelerometer array which have been developed by Los Alamos Labs (Oil and Gas Journal, Jan. 10, 2000), hereby incorporated by reference. Entran make miniature accelerometers with diameters as low as 3.4 mm that could be used in some

application where sensitivity is less critical.

Alternatively, XLTL have proposed to use intelligent coiled tubing drilling to emplace arrays of permanent geophones in designer boreholes. See, www.xltrl.com.

5 According to the invention, the technology developed for dedicated seismic boreholes, is adapted for use in microboreholes.

According to another embodiment, geophones or other sensors are installed in microboreholes to improve
10 the geometry for look-ahead technologies. Conventional look-ahead methods rely on sources and sensors on the drillstring, which suffer from noise, the presence of borehole modes, and the requirement that waves must be scattered in the right direction from features ahead of
15 or around the bit. Placing sensors in microlaterals near the drillface advantageously reduces the drilling or production noise that they experience, eliminates or greatly reduces borehole modes, and improves the geometry. By providing a suitable power supply, sources
20 such as piezoelectric transducers or electric hammers can also be sited in microlaterals.

According to another embodiment, formation fluid sampling is provided with reduced contamination. Conventionally, much of the time spent with sampling
25 tools such as Schlumberger's Modular Downhole Tool (MDT) is aimed at acquiring a hydrocarbon sample free of contamination by drilling fluid filtrate. Since the main borehole is drilled over a long timescale, with dynamic filtration over most of that time, filtrate invasion is
30 deep, and a good deal of fluid must be sucked out of the formation before a clean sample can be obtained. According to the invention, microlaterals are drilled

rapidly, and are then subject to static filtration conditions. A sampling probe inserted at the end of a 2 meter microlateral advantageously avoids the filtrate generated by the drilling of the main borehole, and
5 generates much less filtrate by itself. Sampling using this embodiment is thereby provided in a much quicker and cleaner fashion.

The preferred sequence of operations is as follows: The microlateral is drilled, and the drilling
10 string withdrawn. The tool string is re-positioned, so as to bring a second, sampling module into alignment with the newly-drilled microlateral. This module may be part of the drilling tool string, or may be completely separate requiring complete withdrawal of the drilling
15 tool from the hole. A flexible sampling tube, having a packer seal at its outer end and a means of supplying inflating fluid into the packer seal, is deployed into the microlateral, so as to place the open end of the sampling tube and the packer seal within a few
20 microlateral diameters of the end of the microlateral remote from the main wellbore. The inner end of the sampling tube is connected to a pumping and fluid sample collection & storage system within the tool. Hydraulic fluid is then pumped up into the packer seal, so as to
25 inflate it against the walls of the microlateral, and so create a hydraulic seal preventing any fluid flows along the multilateral between the main body of the microlateral and the end region. Once the packer seal has been set, and sealing verified by observing the
30 response to a small suction, relative to wellbore and reservoir pressure, created by withdrawing a small amount of fluid from the end region into the tool, the main

sample collection operation begins. If the seal is not adequate, the packer is de-pressured, moved slightly in the microlateral, reset, and the test repeated until a satisfactory seal is obtained. The main sample taking
5 operation involves either pumping, or connecting to a sample collection system initially at a pressure lower than that of the reservoir, so as to draw formation fluid from parts of the formation near the far end of the microlateral into the sample collection system within the
10 tool. The composition of the withdrawn stream could be monitored, so as to permit contaminated fluid to be discarded and only relatively pure formation fluid to be stored for transport to surface. Once the sample collection system is filled, the fluid sample is sealed,
15 the packer seal deflated, and the sampling tube withdrawn from the microlateral. The tool is then deployed to the next sampling station or withdrawn to surface.

According to another embodiment, gas or water monitors in horizontal wells are provided. Drilling a
20 set of microlaterals downwards from a horizontal well allows installation of water detectors (e.g., conductivity or dielectric sensors) 2 or 3 meters away from the main borehole, advantageously giving an early and precise warning of the onset of coning or other water
25 movements, and allowing timely control of the production profile in the well to maximize recovery. Microlaterals drilled upwards, with gas detectors (chemical or acoustic, say), provide similar advantages in the case of gas cap encroachment. The environment for the sensors is
30 clean, undisturbed by cementing or other wellbore operations, and the positioning of the sensors is optimal. Conductivity and dielectric sensors for water.

are commonplace technology. Gas detection is preferably performed by attenuation or travel time of an acoustic pulse in the microborehole, generated and detected by acoustic transducers. Conventional devices such as those
5 used by Schlumberger are preferably used.

According to another embodiment, micrologging is provided in microboreholes drilled from horizontal wells. A resistivity logging tool is coupled to the rock bit as it drills the microlateral. Using the resistivity
10 logging tool, a log of the formation variation perpendicular to the main borehole can advantageously be acquired. In a horizontal well, a microlateral upwards or downwards will in this way generate valuable information about the geological environment of the well; for
15 example, where the main borehole lies in relation to a highly permeable payzone. According to a variation of this embodiment, a miniature logging tool is inserted in the hole the microlateral has drilled. It is known using the Schlumberger Cased Hole Dynamics Tester to mount a
20 pressure sensor on the drilling assembly. See web-brochure incorporated by reference above. This type of arrangement is preferably used to carry out the present embodiment with suitable modification for resistivity logging instead of pressure sensing.

25 According to another embodiment of the invention, tracers are injected in the rock formation in microlaterals. Injection of a tracer in one main well and detection of the tracer in a separate main well is often regarded as an important validation for flow
30 models. According to this embodiment of the invention a tracer is injected in a microlateral at a very precise location within a sequence of permeable intervals, to

allow very accurate delineation of flow pathways. This embodiment is especially useful in thinly bedded reservoirs, or reservoirs with thin baffles or conduits. Preferably, tracers are injected in an array of holes to
5 allow the tracer injection to be made at a variety of azimuthal locations around the well. An azimuthally controlled tracer injection could in some circumstances advantageously provide information additional to that from standard, all-azimuth, injection. Preferably a
10 injection tool is provided that can run in the main borehole and inject fluid into individual microlaterals. The tracers are detected in microlaterals using a chemical sensor tailored to the tracer material and is suitably sized to sense the tracer from within a
15 microlateral.

According to another embodiment of the invention, fractured reservoir or individual fracture characterization is provided using microlaterals. A fracture detection log is run in a microlateral, drilled
20 in a fractured reservoir environment. This technique advantageously is used to resolve ambiguity in the geometry and properties of a natural fracture or fracture network inferred from measurements along the main borehole alone. For example, if drilling laterally from
25 a horizontal well showed the presence within 1 or 2 meters of a major fracture, the well can be steered either to intersect it or to avoid it, according to the suspected long distance fluid flow characteristics of the fracture. Similarly, because few vertical fractures are
30 intersected by vertical pilot holes, running fracture detection logs in a plurality of azimuthally distributed microlaterals is used to determine the kick-off direction

for the lateral section. Preferably, the imaging technologies conventionally used for fracture detection are modified for use in the smaller diameter microlateral. One example of imaging technology that
5 could be used with the present embodiment is the borehole viewer for use in holes as small as 50 mm diameter developed by TNO in Delft. See <http://www.tpd.tno.nl/smartsite.html?id=251>), hereby incorporated herein by reference.

10 According to another embodiment of the invention compaction monitoring in horizontal wells is provided using microlaterals. The compaction of soft reservoirs (e.g., chalks) are conventionally monitored by shooting highly radioactive bullets behind the casing,
15 then running a detection tool to observe the slow movement of peaks in the radiation profile. This is expensive, relatively inaccurate and unpopular because of the radioactive material involved. It also does not work in horizontal wells, because the direction of movement of
20 the bullets is vertical, i.e., perpendicular to the wellbore, and so the positions of the radiation peaks wellbore do not change. According to this embodiment of the invention, microlaterals are drilled up and down from a horizontal well, and relatively simple extensometers
25 are installed that directly measure the movements of the formation. Highly sensitive borehole extensometers such as those used in small holes in the tunneling and mining industries are preferably used for the present embodiment. Two or more measurement points should be
30 established in the microlateral, for example by mechanically or chemically anchoring them to the wall. The measurement point closest to the wellbore includes

one or more devices for measuring the distance to the other. For measurement point, for example, a potentiometer varied by a pull wire attached to the remote measurement points, or a linear variable differential transformer (LVDT). If the entire assembly could be placed inside a pressure resistant jacket, then optical or acoustic interference methods for measuring displacement could also be used. For examples, see the range of extensometers made by RST Instruments. See,
10 <http://www.rstinstruments.com>.

According to another embodiment, tilt measurement for hydraulic fracture monitoring or differential compaction monitoring is provided using microlaterals. Companies such as Pinnacle currently
15 offer monitoring of hydraulic fracture geometry by measurement of tilts during pumping, and inversion of the resulting tilt field. The tilt meters are either at the surface (where the sensitivity decreases with depth of the treatment), or in an offset well (which is
20 operationally more complex). According to this embodiment of the invention, a tilt meter is installed in a microlateral of the well being fractured, with a large enough offset from the well to see the effects of a moderately sized frac treatment. Similarly, in fields
25 where production results in reservoir compaction or may trigger tectonic movement, tilt meter installation can complement compaction monitoring to give a larger picture of the strain field in the well-bore vicinity. Tilt meters such as those available from RST (and other
30 geotechnical companies) are preferably modified for use in microlateral hole sizes. See http://www.rstinstruments.com/proddesc/desc_INCL_TiltMeter.htm.

According to a number of embodiments of the invention, various other sensors - electroseismic, streaming potential, temperature, magnetic field and chemical are installed in microlaterals. Preferably, such sensors are installed permanently in the relatively clean and quiet environment of a microlateral. The placement of such sensors in a microlateral also advantageously provides investigation along directions other than that of the main borehole, e.g., to map azimuthal variations of properties around the main borehole. For chemical sensors in particular, the microlateral offers a much cleaner environment, where the sensed fluid has not encountered wellbore fluids. Preferably a large number of multilaterals are drilled at a single location, e.g., like the spokes of a wheel, so wide baselines and azimuthal sensitivity to signals (e.g., tracer arrival) are made possible. Temperature sensors (for example, platinum resistance devices, thermocouples) are in conventional use and can be made extremely small for used in microlaterals, as can chemical sensors. For example, see UK Patent Application No. 0217249.2, Filed 25 July 2002 hereby incorporated herein by reference.

According to another embodiment, monitoring behind expandable tubulars is provided using microlaterals. Expandables are intended to conform to the wellbore shape, so fitting sensors behind them requires extra space. Microlaterals provide the needed space. Preferably, sensors such as those described in the other embodiments of the invention are provided behind an expandable tubular.

According to another embodiment, single interval flowmeters are provided using microlaterals. Since the microlaterals are clean and smooth, flow measurements are made within them, using, for example, MEMS transducers. Placing a microlateral instrumented in this way in each of a number of producing zones (together with perforations for bulk production) allows the contributions of individual zones to be monitored, and allows the effects of a waterflood or other remote treatments to be evaluated in much greater detail (e.g., to tell whether all of a waterflood's effectiveness is in a single interval only).

Flow rate measurement is preferably performed by deploying a Venturi or orifice flow meter within each microlateral, at the end near the main wellbore. In either case, a pressure difference is measured, between an upstream point and, with the Venturi the narrowest point of the flow constriction, or when using an orifice the downstream side of the orifice. A means is provided to transmit data from the flow sensor into the main wellbore and on to surface; this is preferably a direct electrical or fibre optic connection, but alternatively is a short-hop wireless telemetry system. Information on the type of fluid entering the main wellbore is also of value, and this is preferably inferred from measurements made within the microlateral of the density or viscosity of the flowing fluid using MEMS sensors. Other flow measurement methods than those involving measurement of differential pressure are possible, and are familiar to those knowledgeable in the field. Similarly, methods other than those implemented by MEMS are known for density and viscosity measurement.

While the invention has been described in conjunction with the exemplary embodiments described above, many equivalent modifications and variations will be apparent to those skilled in the art when given this disclosure. Accordingly, the exemplary embodiments of the invention set forth above are considered to be illustrative and not limiting. Various changes to the described embodiments may be made without departing from the spirit and scope of the invention.

10

CLAIMS

What is claimed is:

- 5 1. A system for making measurements
associated with a rock formation comprising:
 a main borehole;
 a microborehole extending from the main
borehole into the rock formation;
10 a sensing device positioned and arranged
to make a measurement at a measurement zone being
located in the microborehole away from the main
borehole by a distance of at least the diameter of
the main borehole; and
15 a packer installed in the microborehole
dimensioned and arranged to hydraulically isolate
the measurement zone from conditions present in
other parts of the microborehole and/or main
borehole.

- 20 2. The system of claim 1 wherein the sensing
device is a pressure sensor.

3. The system of claim 2 wherein the sensing
25 device is a pore pressure sensor.

4. The system of claim 3 wherein the rock
formation is a shale formation.

- 30 5. The system of claim 2 further comprising:
 a second sensing device positioned and
arranged to make a measurement at a second

measurement zone being located in the microborehole;
and

5 a second packer installed in the
microborehole dimensioned and arranged to
hydraulically isolate the second measurement zone
from conditions present in other parts of the
microborehole.

6. The system of claim 1 wherein the sensing
10 device is a water sensor adapted to detect the presence
of water in the measurement zone.

7. The system of claim 1 wherein the sensing
device is a gas sensor adapted to detect the presence of
15 gas in the measurement zone.

8. The system of claim 1 wherein the sensing
device is an electrical sensor adapted to detect
electroseismic activity based on measurement of an
20 electromagnetic field in the measurement zone.

9. The system of claim 1 wherein the sensing
device is a streaming potential sensor.

25 10. The system of claim 1 wherein the sensing
device is a temperature sensor adapted to detect the
temperature in the measurement zone.

11. The system of claim 1 wherein the sensing
30 device is a chemical sensor.

12. The system of claim 1 wherein the microborehole is at least one meter long and the measurement zone is at least one meter away from the main borehole.

5

13. The system of claim 12 wherein the microborehole is at least two meters long and the measurement zone is at least two meters away from the main borehole.

10

14. A system for making measurements associated with a rock formation comprising:

a main borehole;

15 a microborehole extending from the main borehole into the rock formation; and

a sensing device at least part of which is positioned in the microborehole away from the main borehole by a distance at least the diameter of the main borehole.

20

15. The system of claim 14 wherein the sensing device is adapted and positioned to detect compaction of the rock formation.

25

16. The system of claim 14 wherein the sensing device is a tilt meter.

17. The system of claim 14 wherein the sensing device is a geophone.

30

18. The system of claim 14 wherein the sensing device is a magnetometer adapted to measure a magnetic field in the microborehole.

5 19. The system of claim 14 wherein multiple measurements are made along length of microborehole using at least the sensing device.

10 20. The system of claim 19 further comprising a second sensing device positioned in the microborehole wherein the multiple measurements are made at least using the sensing device and the second sensing device.

15 21. The system of claim 19 wherein the sensing device is moveable along the microborehole and the multiple measurements are made using the sensing device at a plurality of positions within the microborehole.

20 22. The system of claim 21 wherein the sensing device is a resistivity sensor.

25 23. The system of claim 21 wherein the sensing device is an ultrasonic imaging device adapted to characterize one or more fractures in the rock formation.

24. The system of claim 14 wherein the sensing device is a flowmeter.

30 25. A system for making measurements associated with a rock formation comprising:
a main borehole;

a microborehole extending from the main borehole into the rock formation;

5 a sampling device positioned and arranged to take a fluid sample at a sampling zone being located in the microborehole away from the main borehole by a distance of at least the diameter of the main borehole; and

10 a packer installed in the microborehole dimensioned and arranged to hydraulically isolate the sampling zone from conditions present in other parts of the microborehole and/or main borehole.

26. A system for making measurements associated with a rock formation comprising:

15 a main borehole;

a microborehole extending from the main borehole into the rock formation;

20 an injection device positioned and arranged to inject a tracer at an injection zone being located in the microborehole away from the main borehole by a distance of at least the diameter of the main borehole; and

25 a packer installed in the microborehole dimensioned and arranged to hydraulically isolate the injection zone from conditions present in other parts of the microborehole and/or main borehole.

27. A method of installing a sensor in a rock formation comprising the steps of:

30 drilling a main borehole;

drilling a microborehole extending from the main borehole into the rock formation;

positioning a sensing device in the
microborehole so as to make a measurement at a
measurement zone being located in the microborehole
away from the main borehole by a distance of at
least the diameter of the main borehole; and

installing a packer in the microborehole
to hydraulically isolate the measurement zone from
conditions present in other parts of the
microborehole and/or main borehole.

28. The method of claim 27 wherein the sensing
device is a pressure sensor.

29. The method of claim 27 further comprising:
positioning a second sensing device in the
microborehole so as to make a measurement at a
second measurement zone being located in the
microborehole; and

installing a second packer in the
microborehole to hydraulically isolate the second
measurement zone from conditions present in other
parts of the microborehole.

30. The method of claim 27 wherein the sensing
device is selected from a group consisting of a gas
sensor, a water sensor, an electroseismic sensor, a
steaming potential sensor, a temperature sensor and a
chemical sensor.

31. A method for making measurements
associated with a rock formation comprising making
measurements in a microborehole extending from a main

borehole into the rock formation using a sensing device at least part of which is positioned in the microborehole away from the main borehole by a distance at least the diameter of the main borehole.

5

32. The method of claim 31 wherein the sensing device selected from the group consisting of a formation compaction detector, a tilt meter, a geophone, and a magnetometer.

10

33. The method of claim 31 further comprising the step of making a plurality of measurements along length of microborehole using at least the sensing device.

15

34. The method of claim 33 wherein the step of making a plurality of measurements comprises moving the sensing device along the microborehole and making measurements with the sensing device at a plurality of locations within the microborehole.

20

35. A method of making measurements in a rock formation comprising making measurements at a measurement zone located in a microborehole away from a main borehole by a distance of at least the diameter of the main borehole.

25

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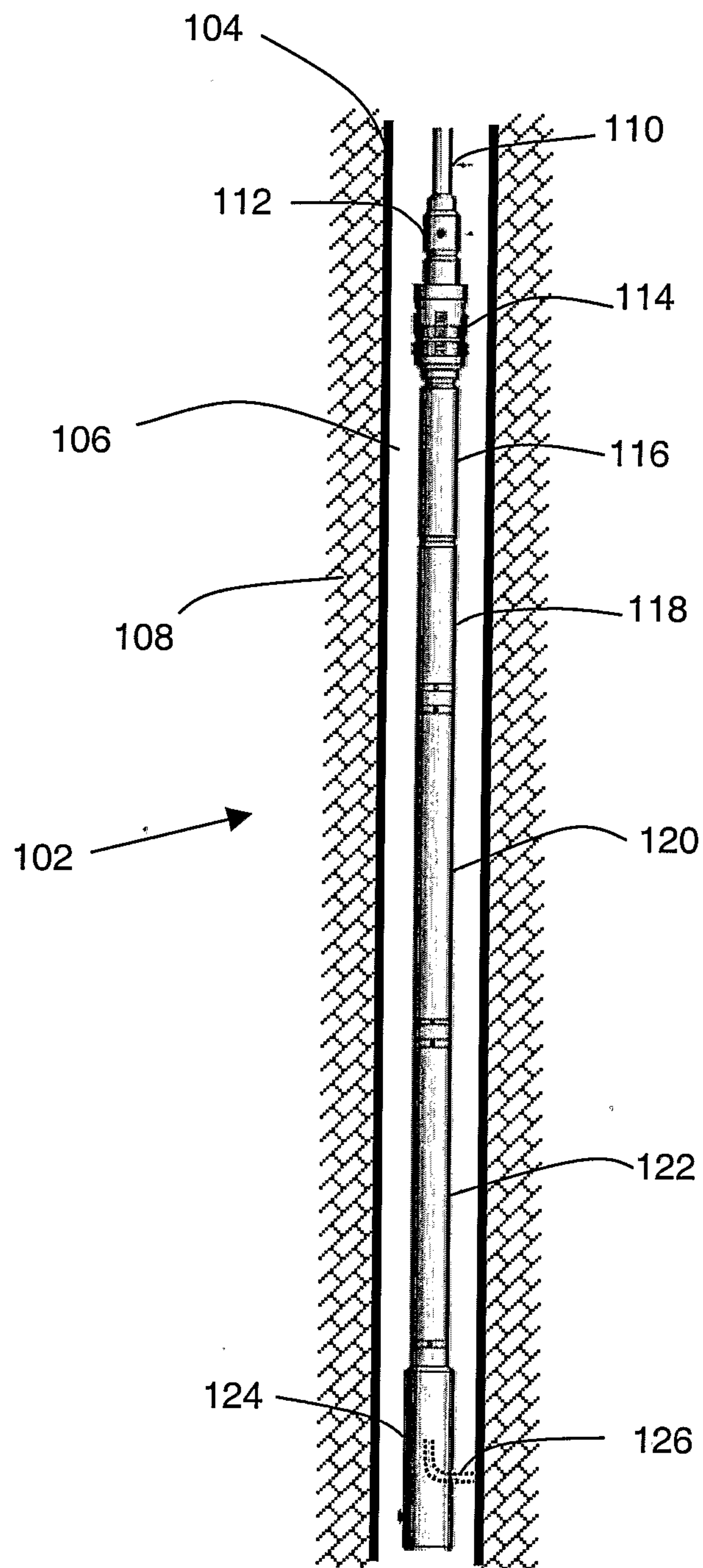


Figure 1

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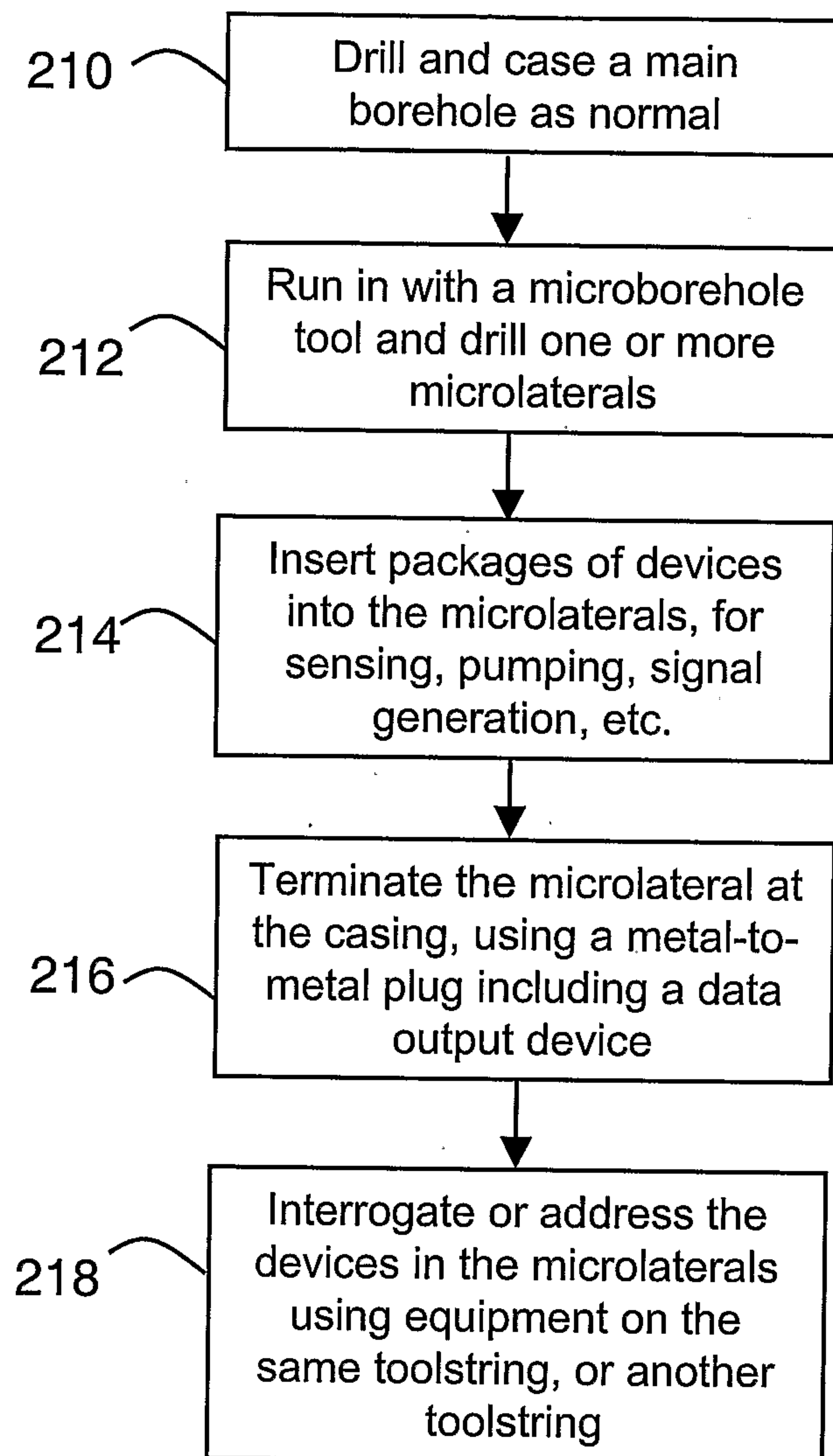


Figure 2

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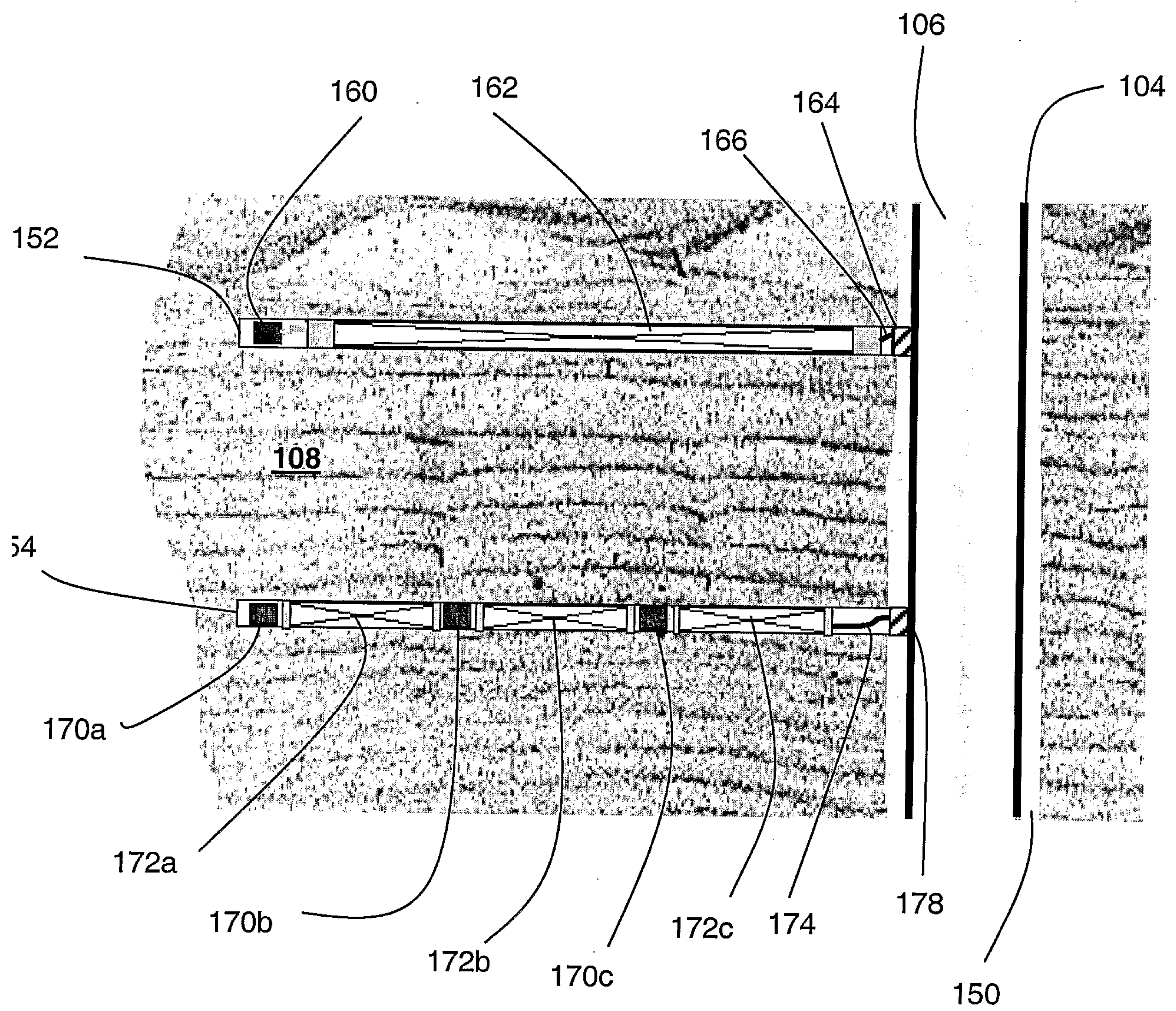


Figure 3

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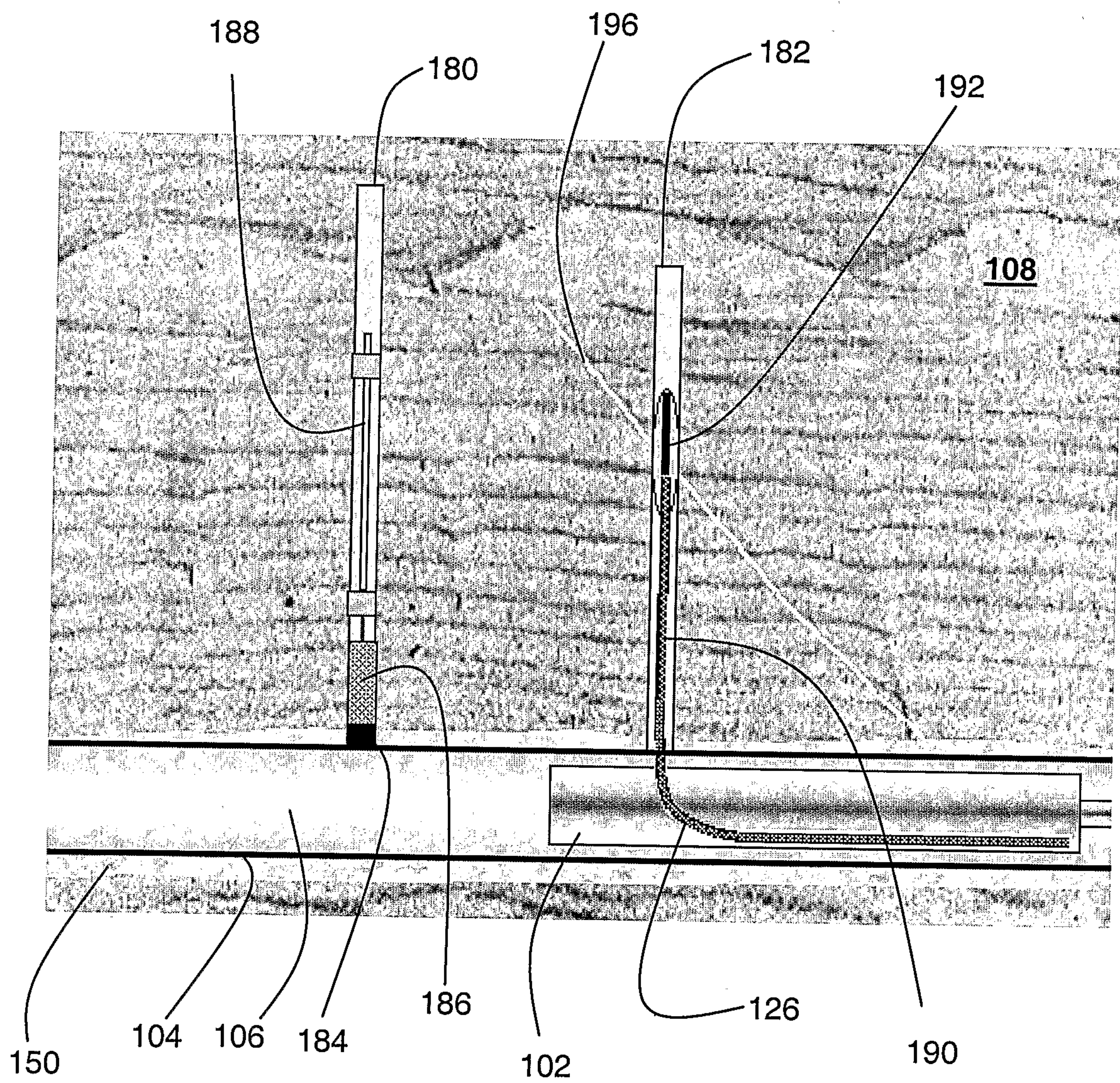


Figure 4

