Feb. 28, 1967 M. P. LEBOURG 3,306,102

FORMATION EVALUATION METHOD AND APPARATUS

Filed Dec. 4, 1963

5 Sheets-Sheet 1

Fig. 2B AFTER FLOW TESTING

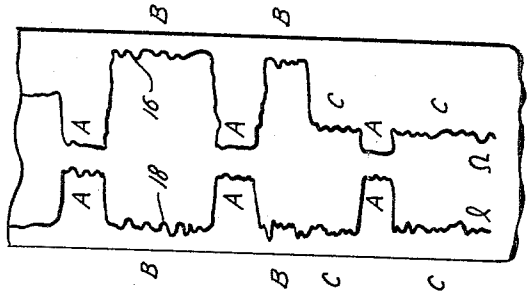



Fig. 1D LOGGING

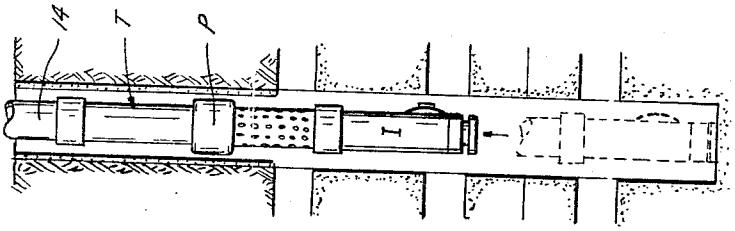



Fig. 1C FLOW TESTING

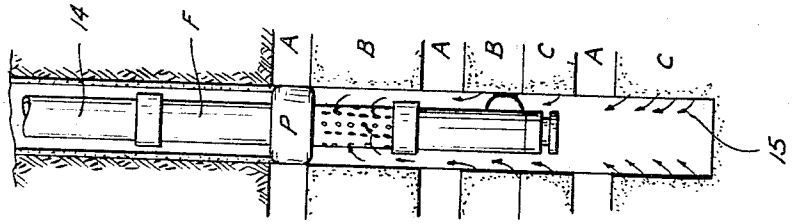



Fig. 2A BEFORE FLOW TESTING

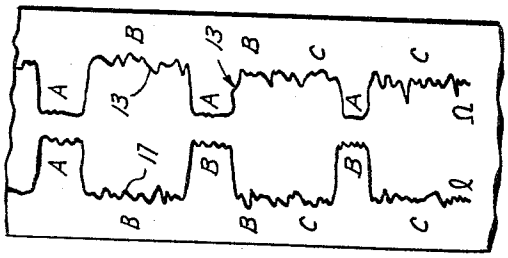



Fig. 1B LOGGING

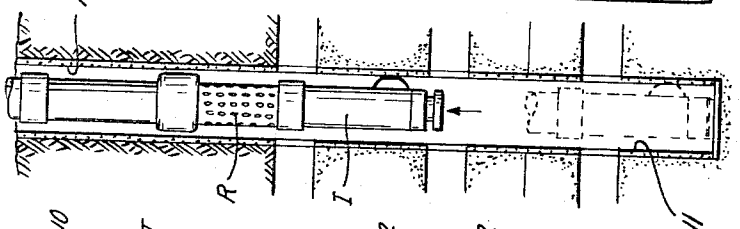
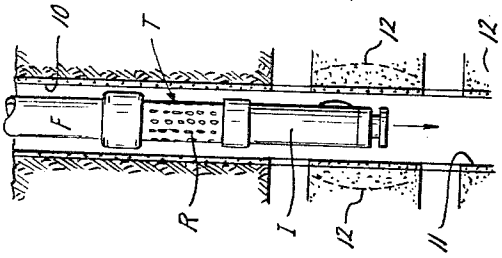



Fig. 1A LOWERING




Maurice P. Lebourg
INVENTOR.

BY

Ernest R. Archambeault Jr.
ATTORNEY

Feb. 28, 1967 M. P. LEBOURG 3,306,102

FORMATION EVALUATION METHOD AND APPARATUS

Filed Dec. 4, 1963

5 Sheets-Sheet 2

Fig. 3

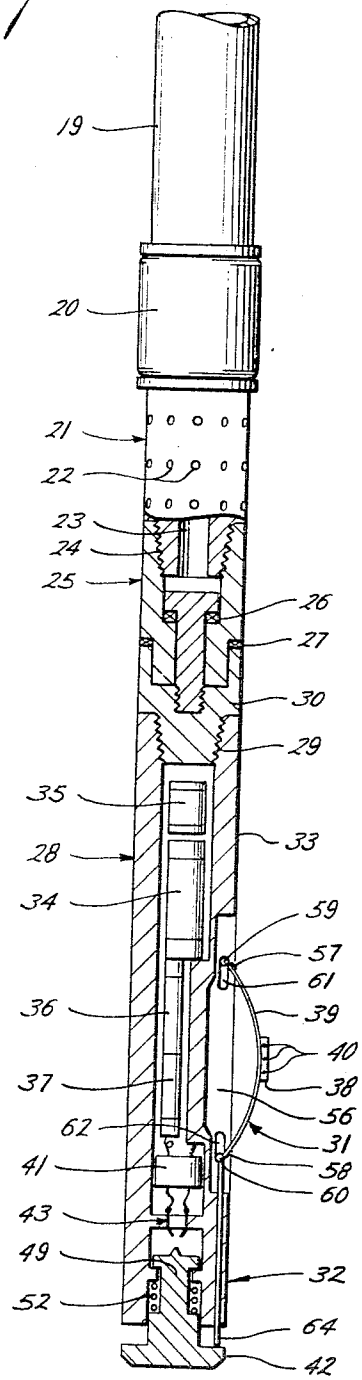



Fig. 1E

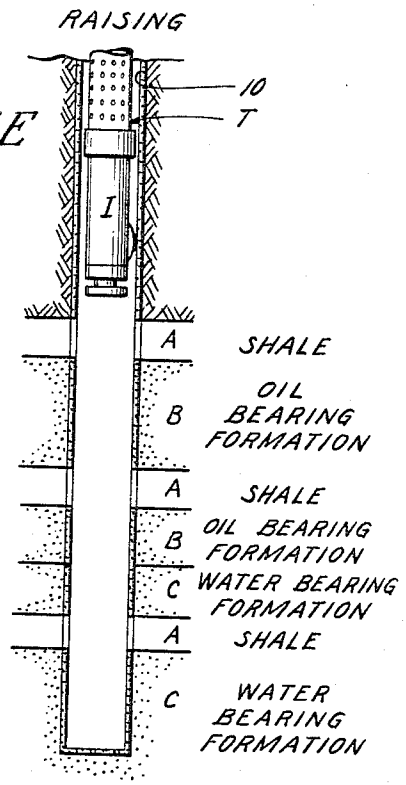
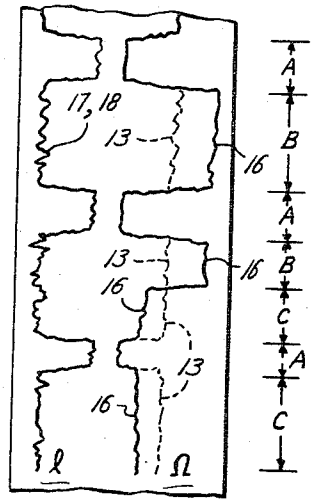



Fig. 2C




Maurice P. Lebourg
INVENTOR.

BY

Ernest L. Reichenbach Jr.
ATTORNEY

Feb. 28, 1967 M. P. LEBOURG 3,306,102

FORMATION EVALUATION METHOD AND APPARATUS

Filed Dec. 4, 1963

5 Sheets-Sheet 3

Fig. 4A

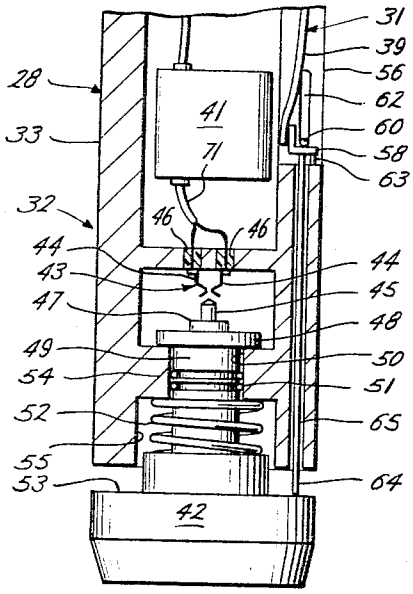



Fig. 4B

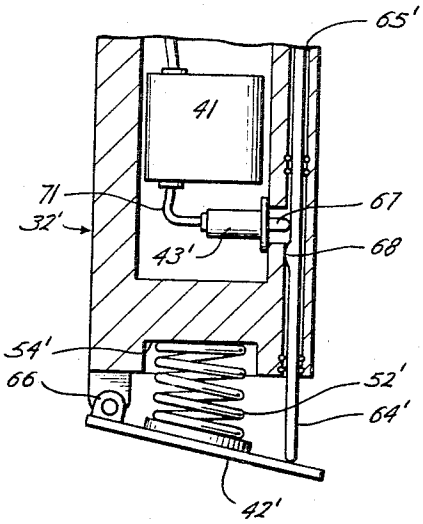
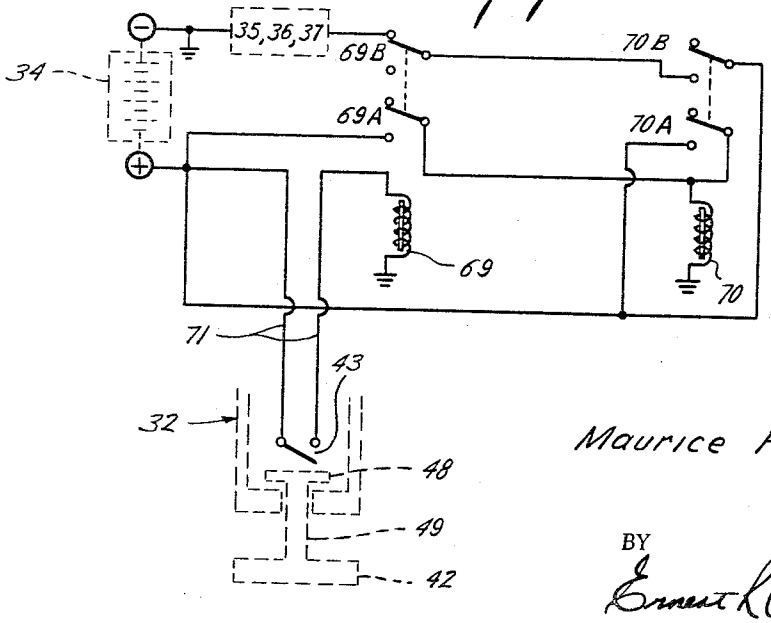



Fig. 5




Maurice P. Lebourg
INVENTOR.

BY
Ernest L Archambeau Jr.
ATTORNEY

Feb. 28, 1967 M. P. LEBOURG 3,306,102

FORMATION EVALUATION METHOD AND APPARATUS

Filed Dec. 4, 1963

5 Sheets-Sheet 4

Fig. 6A

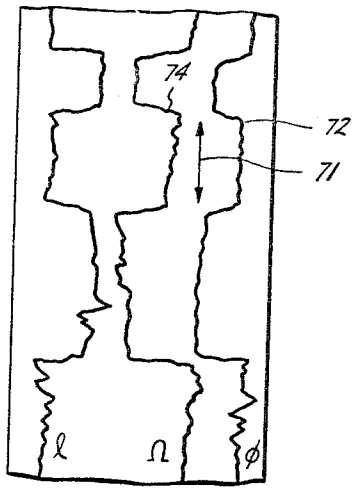



Fig. 6B

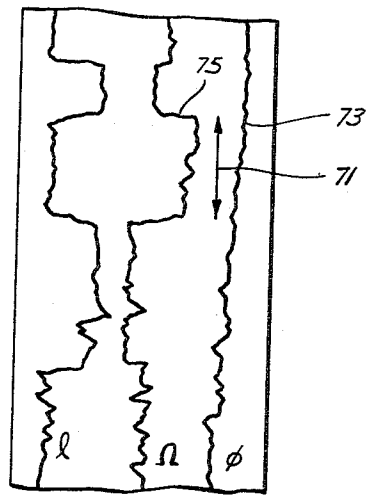
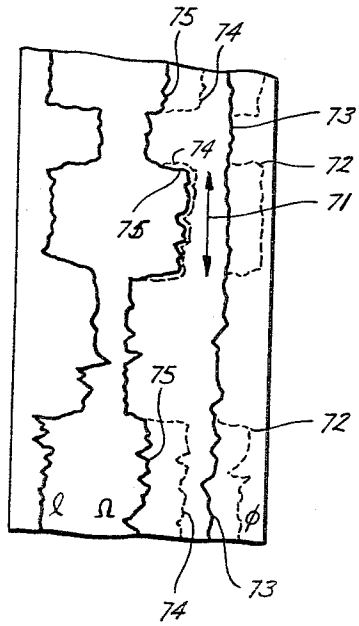



Fig. 6C




Maurice P. Lebourg
INVENTOR.

BY
Ernest R. Archambeau Jr.
ATTORNEY

Feb. 28, 1967 M. P. LEBOURG 3,306,102

FORMATION EVALUATION METHOD AND APPARATUS

Filed Dec. 4, 1963 5 Sheets-Sheet 5

Fig. 7

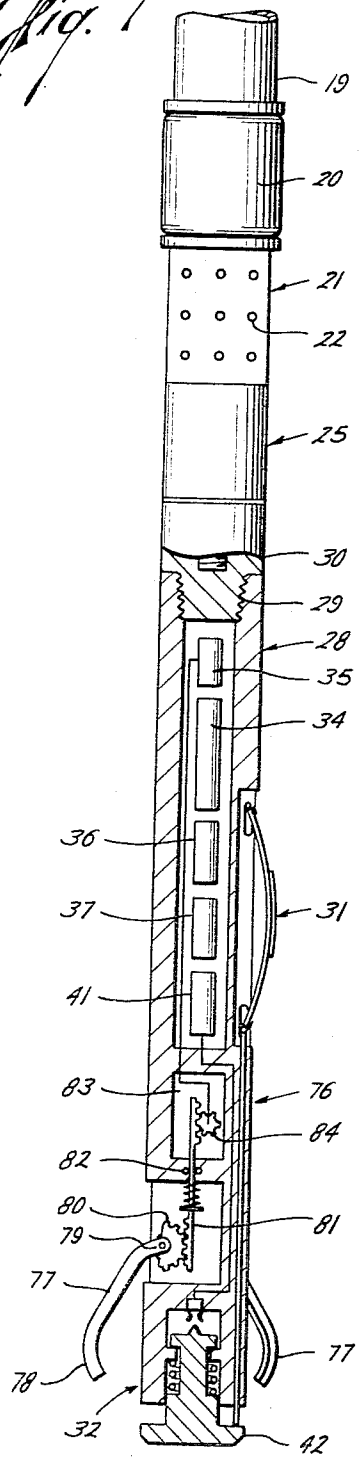
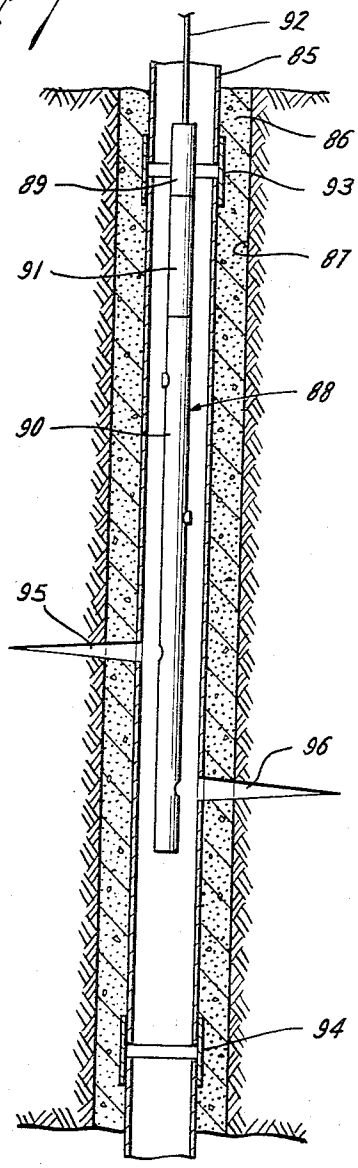



Fig. 8




Maurice P. Lebourg
INVENTOR.

BY

Ernest R Archambeau Jr.
ATTORNEY

United States Patent Office 3,306,102
Patented Feb. 28, 1967



3,306,102

# FORMATION EVALUATION METHOD AND APPARATUS

Maurice P. Lebourg, Houston, Tex., assignor, by mesne assignments, to Schlumberger Technology Corporation, Houston, Tex., a corporation of Texas

Filed Dec. 4, 1963, Ser. No. 327,947
34 Claims. (Cl. 73—155)

This invention relates, in general, to novel methods and apparatus for investigating earth formations traversed by a well bore, and more particularly, to methods and apparatus for investigating earth formations and obtaining characteristic data pertinent to the type of subterranean earth formations and the fluids present within such formations.

While drilling a well, a viscous drilling fluid (known as "mud") is commonly circulated down the drill pipe and back up the annular space between the drill pipe and the well bore. This mud, which is typically a blended composition of high-viscosity organic and inorganic materials, contains a large percentage of suspended solids. The circulated mud removes the earth materials as they are cut-away by the drill bit as well as maintains a hydrostatic pressure within the borehole greater than the natural pressure of fluids contained within any fluid-bearing permeable formations traversed by the borehole.

As is well-known in the art, the higher hydrostatic pressure imposed on the formations by the drilling mud unavoidably forces some of the liquid phase of the drilling mud into any permeable formation strata exposed to the well bore. The solid particles carried in suspension by this liquid are filtered out onto the exposed faces of permeable formations as the liquid or "filtrate" invades the formations. These solid particles continue to build up to form a "mudcake" usually characterized by a very low permeability. In the formation of this mudcake, the filtrate displaces the formation fluids radially away from the borehole.

After a well bore has been drilled, or during the drilling of a well if the drilling string is removed, it is customary to conduct one or more well-logging operations to determine the nature of the various formation fluids and strata traversed by the well bore. These operations typically include the lowering of electrical logging, radioactivity logging or sonic logging devices into the well bore, either separately or in combination, by means of an armored electrical cable. Data obtained from such logging operations is subsequently studied and predictions made therefrom as to the geological nature of the various strata traversed by the well bore, their porosity and permeability, and the type and quantity of fluids contained therein. Experience will then dictate which particular strata are most likely to contain producible hydrocarbons. It is recognized by those skilled in the art that some formation parameters obtainable by logging operations are altered or affected by the presence of a mudcake and by the extent of filtrate invasion. Such measurements as formation resistivity, for example, will be appreciably influenced by the fact that the resistivity of the filtrate will generally be different than the resistivity of the natural or connate formation fluids displaced by the invasion of the filtrate. Furthermore, it is realized that the resistivity of the mudcake itself will be included in the total resistivity measured. Corrections can be made, of course, to determine the resistivity of the unaltered formation with only its connate fluids, but such corrections require making several measurements with the same and different instruments as well as several passages or "round trips" of the instruments into and out of the well bore.

Other types of measurements may be made which are also affected by the extent of filtrate invasion. For example, as shown and described in Patent No. 3,108,188, the presence or absence of saline connate formation water in a particular permeable formation can be predicted. It will be appreciated that such measurements would be affected by invasion of a relatively fresh mud filtrate.



Often it is desirable to supplement or confirm the results obtained from analysis of such formation-logging data by conducting a drillstem test which heretofore has been performed wholly independently of the logging operations. In general, the particular formation zones which warrant testing can be selected by analysis of the logging data. From such drillstem tests, it is then possible to predict the potential production possibilities of those formations tested.

Drillstem tests are conducted by lowering into the well a drillstem tester depending from a string of pipe. The tester includes a suitable packer arrangement adapted for sealing off the annular space between the drillstem tester and the borehole wall to isolate a selected zone from the hydrostatic head of the drilling mud in the well bore above the packer before conducting the drillstem test. After the packer is set, a valve in the drillstem tester is then opened by manipulation of the string of pipe to permit fluids contained within the formations being investigated to flow outwardly therefrom, into the drillstem tester, and on upwardly through the string of pipe which is at a lower pressure than the formation fluids. Measurements of formation pressures are usually made during the drillstem-testing operations by a self-contained downhole instrument. In addition, samples of fluids which flow within the string of pipe are often obtained and analyzed.

The flushing action of formation fluids flowing into the well during a drillstem test is expected to displace most, if not all, of the mud caked on the exposed borehole surfaces of the fluid-bearing permeable formations along the isolated section as well as to force out the mud filtrate which has invaded these formations. After such flushing, one may expect to recover the connate fluids naturally contained within the permeable formations. Following a drillstem test, conditions within the well again stabilize as the drilling mud filtrate reinvades the permeable formations with the attending redepositing of the mudcake. The length of time required for this reinvasion and recaking process is variable since this time interval will be dependent upon many factors such as porosity, permeability, formation pressures, types of drilling muds, etc. Those skilled in the art do recognize, however, that this re-establishment of conditions or restabilization generally takes place in a relatively short time.

The time required for restabilization is generally too short, however, to obtain logging data of the formations in their unaltered condition by conventional methods which would necessitate first removing the drill string a section at a time to retrieve the drillstem tester and then repositioning a formation-logging instrument into the well bore, all of which would consume an appreciable amount of time. Furthermore, even if such logs were made, there would be no way to accurately predict what compensating corrections would be required, not knowing the extent of filtrate reinvasion during the time required to remove the drillstem tester and reposition the logging instruments. It will be appreciated, moreover, that it is economically desirable to reduce the amount of time that drilling or other operations on a well are suspended while conducting such logging and testing operations.

It is, therefore, an object of the present invention to provide new and improved methods for investigating the natural characteristics of permeable earth formations and for assisting in the completion of a well.

It is also an object of the present invention to provide new and improved systems for determining the natural characteristics of earth formations which require only a single round trip into and out of the well bore.

A further object of the present invention is to provide new and improved systems for obtaining formation data which is useful in predicting the production potential of a particular well and for assisting in the completion of that well.

Another object of the present invention is to provide new and improved systems for obtaining data which is indicative of characteristics of permeable formations without the influence of drilling mud or mud filtrate.

Still another object of the present invention is to provide new and improved systems for determining the effects of filtrate invasion as well as the flow characteristics of a well.

It is yet a further object of the invention to flow fluids from the earth formations and, before any substantial mudcake and filtrate invasion can reoccur, perform a series of logging operations to obtain formation data relative to the natural formation fluids contained therein.

The novel methods of the present invention are practiced by first reducing the well bore pressure opposite a particular formation interval to be investigated to allow the fluids contained in the permeable formations in that interval to flow into the well bore. This flow is maintained until the connate formation fluids have substantially displaced the drilling mud filtrate which had previously invaded the formations and washed away the accumulated mudcake along the wall of the well bore. Then, before any substantial reinvasion of filtrate can occur, a series of measurements are taken along the formation interval of those formation properties or characteristics which are altered or affected by the invasion of mud filtrate within the permeable formations.

The particular interval tested can be along any section or all of the well bore if so desired. Additionally, a first series of such measurements may be taken before the flowing step as well as taking a second series afterward if it is desired to obtain correlative data which will be indicative of the effects of filtrate invasion and the flow characteristics of the formations tested. Where it is preferred, additional measurements may also be made of formation properties not affected by filtrate invasion simultaneously with the first and second series of measurements for aid in correlating the first and second series and for purposes of reference in subsequent completion operations.

A preferred form of apparatus to be used in practicing the novel method disclosed herein is made by combining flow-testing apparatus with formation-logging apparatus so that the combined apparatus can be controlled from the surface while suspended in a well bore on a string of pipe for containing the fluids produced from the formations. The flow tester preferably includes a packer means to isolate a formation interval to be tested and a selectively-operable valve to control flow between the tested interval and the string of pipe. This type of flow apparatus can be found in a conventional drillstem tester. The formation-logging apparatus need have only a single instrument, for example, a chloride-ion measuring device or a formation-resistivity measuring device, but preferably also includes a gamma-ray radiation detection device. Self-contained recording instruments are provided for recording of data.

The novel features of the present invention are set forth with particularity in the appended claims. The present invention, both as to its organization and manner of operation together with further objects and advantages thereof, may best be understood by way of illustration and example of certain embodiments when taken in conjunction with the accompanying drawings, in which:

FIG. 1A illustrates a testing apparatus being lowered into a well;



FIG. 1B illustrates a testing apparatus logging a well bore in which a mudcake has formed and mud filtrate has invaded the permeable formations;

FIG. 1C illustrates a testing apparatus during a flow testing operation;

FIG. 1D illustrates a testing apparatus being used to obtain a log before mudcake has reformed and filtrate has reinvaded the permeable formations;

FIG. 1E illustrates a testing apparatus being removed from a well;

FIG. 2A shows typical formation logs or films strips representative of measurements recorded in the logging step illustrated in FIG. 1B;

FIG. 2B shows typical formation logs or film strips representative of measurements recorded in the logging step illustrated in FIG. 1D;

FIG. 2C shows the typical formation logs or film strips of FIGS. 2A and 2B combined with one another to illustrate the differences between logs obtained prior to the flow testing and after the flow testing;

FIG. 3 is a longitudinal view, partly in section, of an embodiment of testing apparatus of the present invention, the parts being shown in the relative positions occupied while the testing apparatus is within the well bore;

FIG. 4A shows an embodiment of a switching assembly used for controlling the apparatus shown in FIG. 7;

FIG. 4B shows an alternative embodiment of a switching assembly;

FIG. 5 shows a relay circuit which may be used in controlling the electrical circuitry;

FIG. 6A shows typical formation logs or film strips such as those of FIG. 2A with an additinal record;

FIG. 6B shows typical formation logs or film strips such as those of FIG. 2B with an additional record;

FIG. 6C shows the typical formation logs or film strips of FIGS. 6A and 6B combined with one another to illustrate the differences between logs obtained prior to the flow testing and after the flow testing;

FIG. 7 is a longitudinal view, partly in section of another embodiment of testing apparatus of the present invention which is similar to the embodiment shown in FIG. 3 but with the addition of a calipering logging device; and

FIG. 8 is a longitudinal view of a perforating tool being used to practice a method of the invention.

In practicing the method of the present invention, a testing apparatus T is lowered into a well bore **10** as shown in FIG. 1A. The apparatus preferably includes a flow tester F, a packer P, a perforated pipe R and a formation-logging instrument I. The section of earth formations to be investigated as shown in FIGS. 1A–1E (identified only in FIG. 1E) may include permeable oil-bearing earth formations B and permeable water-bearing formations C separated by impermeable shale formations A. The exposed faces of permeable formations B and C are coated with a mudcake **11** and mud filtrate has invaded these zones to a depth indicated at **12** (FIG. 1A). The predetermined zone to be investigated is assumed to include these designated formations.

As seen in FIGS. 1A and 1B, the testing apparatus is first lowered to the bottom of the well bore (as shown by the dotted lines in FIG. 1B) and then raised to a level where the packer P is at least above the upppermost permeable earth formation B. During this traverse, the electrical resistivity of the formations is measured and a self-contained recorder (not shown) in the formation-logging instrument I records the measured resistivity values as the apparatus is traversed along the well bore. The record of resistivity so produced is illustrated in the right-hand curve **13** of FIG. 2A.

Next, as seen in FIG. 1C, the apparatus is stopped at the predetermined depth just above the zone being investigated, and the packer P is expanded to isolate the section of earth formations below upper permeable formation A from the well bore **10** above the packer P. The string

of pipe 14 is then manipulated relative to the set packer P to open a valve (not shown) in the flow tester F. Opening of this valve permits fluids to flow (as indicated by arrows 15) from within the permeable formations through the perforated pipe R and on into the string of pipe 14. The tester valve is left open for a sufficiently-long time period for the filtrate to flow out of the formations and to ensure that formation fluids have entered the string of pipe 14.

Following the flowing operation, as seen in FIG. 1D, the packer P is released and the apparatus T again lowered and raised, as described before. During this second upward movement, the formation resistivity is again measured. Since this step immediately follows the flowing operation and the well has not yet restabilized, this second logging operation is conducted before either a new mudcake has formed or filtrate has reinvaded the formations. Thus, as shown by the right-hand curve 16 of FIG. 2B, a second record of resistivity is obtained in a manner similar to that described heretofore.

Following this second logging operation, the apparatus T is retrieved, as shown in FIG. 1E, and the record or log of FIG. 2A can be correlated with that of FIG. 2B. Each particular formation stratum along the section investigated must, of course, be precisely located in order that logging data from the two logging operations can be correctly correlated.

One manner in which this correlation can be done is to "touch bottom" (as shown by dashed lines in FIGS. 1B and 1D) with the test apparatus T and then measure the travel required to bring the apparatus to the top of the zone being investigated. By conducting the logging operations at a known rate of travel, and by starting each operation from a known point, each stratum can be accurately located since the recorder chart moves at a known constant rate.

This illustrative manner of locating the particular formation strata assumes, of course, that only a single logging instrument is being used in the testing apparatus. It is preferable, however, to include a gamma-ray logging instrument with the apparatus to measure the natural radioactivity of earth formations and to record these detected measurements simultaneously with the resistivity measurements. Typical gamma-ray logs are shown in the left-hand curves 17, 13 respectively, of FIGS. 2A and 2B. Natural radioactivity is more predominent in shale than in other types of formations and the gamma-ray logs consequently clearly delineate the shale formations at A from the non-shale formations at B and C. Since the level of natural radioactivity is relatively unaffected by the flowing operation, correlation of the resistivity logs is easily and positively accomplished.

Regardless of how the particular strata are correlated to depth, the logging data of FIG. 2A may be correlated with that of FIG. 2B either by transposing one log onto the other, by super-imposing one log over the other, or by simply comparing measured values. In any event, a typical correlation by combining the logs of FIGS. 2A and 2B is illustrated in FIG. 2C which permits the formation interval to be evaluated as follows:

(1) Formations A maintain the same resistivity and are clearly delineated by a high level of natural radioactivity (curves 17, 18) and relatively low resistivity (curves 13, 16). Thus, formations A are shale because shale is known to have a high level of natural radioactivity, a low resistivity and, being impermeable, is unaffected by drilling mud.

(2) Formations B show a substantial increase in resistivity following the drillstem test (curve 16) over the resistivity measured before the drillstem test (curve 13). Radioactivity is relatively low. Thus, formations B are permeable and fluid-bearing since the flowing operation had a marked influence on the resistivity of these formations. The natural fluids within these formations are most likely hydrocarbons since hydrocarbons are known to



have a high resistivity and the flowing operation has caused an increase in resistivity indicating displacement of the mud filtrate by a higher resistivity fluid.

(3) Formations C show a significant decrease in resistivity following the drillstem test which moreover is substantially lower than the resistivity of formations B. Radioactivity is relatively low. Thus, as in (2) above, these formations are also permeable and fluid-bearing. The connate fluids within these formations are most likely water, however, since connate water at these depths is generally saline and accordingly has a resistivity substantially lower than the resistivity of hydrocarbons. In the present example, it is assumed that the drilling mud chosen for use in the well is relatively "fresh" and that the mud filtrate has a resistivity at least slightly higher than that of the connate formation water. Thus, the flowing operation produced a decrease in resistivity from that of the first series of measurements, indicating displacement of mud filtrate by formation water.

Other comparisons could be made with other types of formations by using known properties or characteristics of such formations. For example, impermeable formations other than shale would show no change in resistivity but would have only a low level of radioactivity. It is also likely that gaseous hydrocarbons would show a higher resistivity than liquid hydrocarbons.

There are, of course, certain variations possible in practicing the invention which nevertheless fall within its spirit and scope. For example, although the present invention is primarily concerned with conducting logging operations only along the particular formation interval being investigated, it would be feasible nevertheless to use the testing apparatus to log the entire span of the well bore as testing apparatus T is either being lowered in or retrieved from the well bore, or both, in addition to logging the particular zone of investigation. These instruments could, of course, be radioactivity or sonic logging instruments as well as electrical logging instruments.

Furthermore, it is not necessary to the invention, that the logging operations be performed in any particular manner or limited to any particular number. Also, although it is preferable, it is not essential that any logging operation be made with testing apparatus T prior to the drillstem-testing operation, for it may be preferred that formation logs previously made with electric cable instruments in the conventional manner be substituted for the logging operations made with the apparatus of the present invention prior to the flowing operation since, in either case, the well would be stabilized.

The foregoing discussion has been directed to obtaining a first series of logging data before the flowing operation to measure the formation properties in their stabilized condition while affected by an invasion of drilling fluid and then, after the flowing operation, obtaining a second series of logging data before the conditions have restabilized. Although this sequence will permit the complete operation to be conducted in the minimum amount of time, it should be realized that the sequence could be reversed to obtain the same data as well as additional data.

This reversed sequence would entail performing the flowing operation initially and then, before the well has restabilized, obtaining the first series of logging data. The apparatus would be held in position until the well had restabilized and then the second series of logging data would be obtained to measure the change in properties as affected by the invasion of drilling fluid. If desired, several series of logging operations could also be performed at spaced time intervals as the well was stabilizing to obtain useful data which would be indicative of the relative speed at which reinvasion occurred in the various strata.

The preferred manner of practicing the invention is to use a gamma-ray logging instrument in cooperation with a resistivity-measuring instrument. Among other things,

this makes it unnecessary to measure depth. It is also preferable to start the operation of the aforementioned instruments and the recorder by a downhole switch. In this connection, a switch coupled to the lower end of the tool is operated by contact with the bottom of the well bore or with an obstruction therein such as a bridge plug previously set below the formation zone to be investigated. The switch could also be operated by rotary motion or by signals from the surface. As it is clearly desirable to avoid running electrical conductors, such signals from the surface could be in the form of acoustical impulses to trigger a frequency-responsive downhole switch. Moreover, it will be appreciated that the formation-logging instrument could be any of the presently-known devices which measure characteristics of earth formations in dependence upon the character of the fluid content such as a chloride-ion logging device.

As illustrated in FIG. 3, in the preferred embodiment of the apparatus, the flow tester may be any type of drillstem tester **19**, such as those shown and described in either the B. P. Nutter Patent No. 2,901,001 or the N. K. Andrew Patent No. 3,051,245. The packer **20** on the drillstem tester **19** may be a conventional expanding-type packer element made of rubber or rubber-like material. The packer is arranged so that when expanded, it will sealingly engage the walls of the borehole **10** to isolate an interval along the well bore below the packer from the hydrostatic pressure of the mud column above the packer.

Dependently secured below packer **20** is a conventional perforated anchor pipe **21** having a plurality of lateral ports **22** arranged to permit well fluids to flow therein and on into drillstem tester **19** by way of internal bore **23**.

Anchor pipe **21** is threadedly connected at **24** to swivel joint **25** which is arranged to rotate freely on bearings **26** and **27**. Swivel joint **25** is provided to minimize or eliminate rotation of the tester relative to formation-logging instrument **28** while drill pipe **14** is manipulated to seat and unseat packer **20** and to actuate the valve in the drillstem tester **19**.

Dependently secured by threads **29** to tail piece **30** of swivel joint **25** is formation-logging instrument **28** on which is secured pad assembly **31** and switch assembly **32**. Formation-logging instrument **28** includes an outer housing **33**, preferably of metal, which encloses batteries **34**, data recorder **35**, and any one or more of conventional logging instruments such as, for example, gamma-ray logging instrument **36** and electrical-resistivity measuring circuits **37** in separate compartments. These logging instruments and circuits **36**, **37**, each detect particular properties characteristic of the formations proximate to logging instrument **28** and convert these results into electrical signals representative thereof. These electrical signals are then recorded on data recorder **35**, which may be any conventional type of film, tape, wire, etc., machine normally used in the art. If housing **33** is metal, the exterior may be coated with an electrical-insulating material, such as epoxy resin or some similar compound, to prevent the metal body from short-circuiting electrical current during resistivity measurements. Typical resistivity logging apparatus which can be employed is shown in U.S. Patent No. 2,669,688, an unfocused system, or the focused system shown in U.S. Patent No. 2,712,629. Typical gamma-ray logging apparatus is shown in U.S. Patent No. 2,349,225.

Pad assembly **31** includes an insulated wall-engaging pad **38** attached to housing **33** by a strong bowed spring **39** which is also coated with an electrical-insulating material. Pad **38** is attached approximately at the midpoint of spring **39**. Embedded in the wall-engaging face of the pad **38** is a plurality of spaced-apart button-type electrodes **40**. Electrodes **40** are nearly flush with the wall-engaging face of pad **38** or may be slightly recessed.

At the lowermost extremity of logging instrument **28**, switching assembly **32** is arranged so that electrical power may be turned on as desired to supply power to the various components within logging instrument **28**. Switching assembly **32** includes a relay assembly **41** which may be a conventionally-arranged holding circuit, as shown in FIG. 5, for maintaining power to the components after momentary initiation of switching assembly **32**. If desired, the relay assembly **41** could be the one disclosed in a co-pending application, Serial No. 328,072 filed December 4, 1963, by Fred Pehoushek and assigned to Schlumberger Well Surveying Corporation, which permits selective turning-off of the instruments as well as selective turning-on of the instruments.

Relay assembly **41** is compartmentized to protect the components therein. Initiation of relay assembly **41** is accomplished by actuating contact member **42** to momentarily close switch **43**. In the particular embodiment shown in FIG. 4A, switch **43** includes two or more resilient electrical contacts **44** spaced apart from one another in such a manner that male conductor **45** will bridge the gap between the contacts **44** whenever contact member **42** moves upwardly. Contacts **44** and male conductor **45** are insulated from the housing **33** by means of insulators **46**, **47**, respectively. Male conductor **45** and insulator **47** are centrally located on top of an enlarged portion **48** of cylindrical plunger member **49** which is received in bore **50** of switch assembly **32** and centrally located on top of contact member **42**. The annulus between bore **50** and cylindrical plunger **49** is sealed by means of O-rings **51**. Compression spring **52** encircles plunger **49** and is held between the upper face **53** of contact member **42** and the lower side of shoulder **54** of spring recess **55** thereby biasing contact member **42** downwardly until enlarged portion **48** of plunger member **49** rests on the upper side of shoulder **54**.

Bottom contact member **42** also serves to release pad assembly **31** from its retracted position in recess **56** in housing **33** upon the initial contact of contact member **42** with the bottom of borehole **10**. Although it is not necessary, it is preferred that pad assembly **31** be retracted for its protection when the testing apparatus is first lowered into borehole **10**.

The outer ends of bowed spring **39** are fixedly attached to hinge members **57**, **58** which slide freely on hinge pins **59**, **60** loosely received in pairs of longitudinal slots **61**, **62** cut in opposite sides and at both ends of recess **56**. In the retracted position of pad assembly **31**, as partially shown in FIG. 4A, lower hinge member **58** is held at the bottom of slots **62** to housing **33** by a shear pin **63** which is sufficiently strong to constrain bowed spring **39** in its extended position as shown. Actuating or thrust rod **64** is received in longitudinal bore **65** which extends through the outer portion of housing **33** from the lower end of recess **56** to the exposed lower end of switching assembly **32**. The upper end of thrust rod **64** contacts the under side of lower hinge member **58** while resting freely on upper face **53** of bottom contact member **42**. Thus, it will be appreciated that when it is desired to engage pad **38** with the side of borehole **10**, bottom contact member **42** is engaged with the bottom of borehole **10** or with an obstruction, such as a bridge plug. When the combined weight of drill pipe **14** and the testing apparatus is applied against this obstruction, bottom contact member **42** is thrust upwardly against spring **52** to move thrust rod **64** upwardly and snap shear pin **63**. Failure of shear pin **63** frees lower hinge member **58** and permits it to move upwardly in slots **62** toward upper hinge member **57** as spring **39** bows outwardly into its extended position, as illustrated in FIG. 3.

In FIG. 4B, an alternate embodiment **32'** of switching assembly **32** is shown. Switching assembly **32'** is similar to switching assembly **32** except that bottom contact member **42'** is a flat plate pivoted at **66** to the lower end of switching assembly **32'**. Momentary-contact switch **43'** is arranged so that actuator **67** is moved inwardly when

engaged by cammed surface 68 on thrust rod 64' as it and contact member 42' move upwardly.

Other switching means can, of course, be arranged. For example, switch 43 of FIG. 4A could be replaced with a momentary-contact switch such as 43' of FIG. 4B.

The relay assembly 41, as illustrated in FIG. 5, will maintain power from batteries 34 to recorder 35, gamma-ray logging instrument 36 and resistivity-measuring circuits 37 after the initial engagement of contact member 42 with the bottom of the borehole. The relay assembly includes a starting relay 69 and a holding relay 70, both of which are conventional double-pole double-throw relays. Conductors 71 from switch 43 connect the coil of relay 69 with the power supply or batteries 34 carried within the instrument whenever switch 43 is closed to energize relay 69. Relay switch 69A closes and completes a path between the power supply 34 and the coil of relay 70, which energizes that relay. Relay switch 70A thereby closes to complete another path from the power supply 34 to the coil of relay 70. Relay switch 70B also closes at the same time which would complete a path from the power supply to electrical circuitry 35, 36 and 37 if it were not for the fact that relay switch 69B is now open since relay 69 is still energized. It will be appreciated, therefore, that as soon as relay switch 69B closes in response to the opening of switch 43 and subsequent de-energizing of relay 69, a complete path will be made from power supply 34 through relay switch 70B and relay switch 69B to electrical circuitry 35, 36, and 37.

While the foregoing disclosure has illustrated the apparatus as operating in a well bore which has a relatively stable and well-packed bottom, the bottom of a well bore is often filled for several feet with cuttings, loose debris, etc., which may not be sufficiently consolidated to sustain the large forces required to set the packer element of a drillstem tester. When such forces are applied to set the packer, the bottom of the tool may be driven through the bottom of the hole and for several feet into the earth formations with the result that the packer may be finaliy set an appreciable distance below the top of the formation zone being investigated. Heretofore, an operator had no accurate indication of the amount of such displacement nor whether the packer had been set where it would not block production from permeable strata uppermost within the formation interval being investigated.

Using apparatus of the present invention, however, it will be appreciated that when logs are made before and after the flowing operation, the effect of such displacement of the tool upon setting of the packer will be evidenced by a longitudinal shift between the logs. Since the distance between the packing element and logging instrument is fixed by the tool configuration, the precise point where the packer was set can be readily determined by correlating the first and second series of radioactivity logs to determine the amount of displacement of the tool relative to the bottom of the well bore.

An alternate variation in practicing the invention involves including a bore-diameter measuring or calipering operation in conjunction with the radioactivity logging operation and, if desired, the resistivity logging operation.

As previously described, the flushing action during the flowing operation will displace most, if not all, of the mud caked along the exposed faces of the fluid-bearing permeable formations within the isolated zone. Thus, it is within the scope of the present invention to obtain logs of the borehole diameters in addition to the other measurements previously discussed in detail. Accordingly, it will be appreciated that one series of diameter measurements will vary from the other series only by the thickness of the mudcake deposited along the permeable zones and that such a change in the measured diameter will be obtained only along those fluid-bearing permeable strata from which fluids were produced during the flowing operation.



It will be understood that combination of calipering or measuring with only the radioactivity logging will merely indicate whether a particular strata is a permeable formation capable of producing a connate fluid which might be either water or hydrocarbon. Thus, it is preferred to combine the calipering operation with both the radioactivity and resistivity logging operations. A series of three logging curves will be obtained for each of the logging runs and accordingly present a more detailed picture of changes in the formations as a result of the flowing operation.

A typical set of logging curves is sequentially presented in FIG. 6, with FIG. 6A illustrating the logging data obtained when the well is stabilized, FIG. 6B depicting the logging data obtained immediately after the flowing operation and before the well has stabilized, and FIG. 6C showing the curves of FIGS. 6A and 6B superimposed or combined for correlation. Although FIG. 6C shows a marked variation along curve portion 71 between the diameter-measuring logs represented by curves 72 and 73 of FIGS. 7A and 7B, respectively, it will be noted that resistivity curves 74, 75 fail to exhibit any appreciable variation along curve portion 71. It will be appreciated that in the absence of the diameter-measuring logs, it would probably be assumed that the particular strata associated with curve portion 71 were either impermeable or at best non-producing since there was little or no change in resistivity. The appreciable differences between the calipering log curves 72, 73, however, quite clearly indicate that there most likely is a producing permeable formation at this point since the changes in diameter are most likely attributable to the flushing away of a mudcake.

It will be understood by those skilled in the art that such instances of little or no change in resistivity of a fluid-bearing permeable formation could occur, for example, whenever the resistivity of the mud filtrate was substantially equal to that of the connate formation water. Thus, although connate formation water had displaced mud filtrate from the invaded zone during the flowing operation, the resistivity of the formation would exhibit little or no change. The addition of a calipering log will accordingly assist in the detection of such conditions and eliminate the possibility that a permeable fluid-bearing formation has been overlooked

FIG. 7 schematically shows an assembly of instruments and apparatus which would serve to obtain the calipering logs discussed above. The apparatus of FIG. 3 has been incorporated with a conventional calipering device 76 which could be patterned, for example, after the apparatus disclosed in Patents No. 2,102,080 and 2,267,110, for example. Calipering device 76 preferably includes three symmetrically-arranged independent feeler arms 77 with each having either an outwardly-disposed pad member at its outer end or being curved, as at 78, to permit the tool to be raised and lowered in the well bore. The upper end of each arm 77 is pivoted, as at 79, and provided with a semi-circular gear segment 80. Each gear segment 80 drives a downwardly-biased reciprocable plunger 81 having rack teeth on its lower end in engagement with the gear 80. The plungers 81 project upwardly from the gears 80, through a sealing member, such as O-ring 82, into a sealed chamber 83. Rack teeth on the upper end of each plunger 81 are drivingly engaged with a potentiometer 84 which is arranged to vary in resistance in accordance with the movement of feeler arm 77. Potentiometers 84 are incorporated in a standard bridge circuit (not shown) and connected to recorder 35 in the well-known manner. If desired, the feeler arms 77 could be left free as the tool was lowered in the well bore, but it is preferred to releasably hold them against the side of the tool until the pad assembly 31 is released. A thrust rod (not shown) similar to the thrust rod used to release pad assembly 31 or some similar releasing arrangement as shown in Patent No. 2,102,080 could be employed to

release feeler arms **77** when contact member **42** is first engaged with the bottom of the borehole.

A further aspect of the present invention is seen in FIG. 8 where a casing **85** has been cemented, as at **86**, in place in an open well bore **87** in the usual manner. Following this, a tool **88** including a radioactivity detecting and measuring device **89** and a conventional perforating apparatus **90** equipped with casing-collar locator **91** is lowered into the casing on a wireline **92**. This tool is lowered to the bottom of the well to obtain a radioactivity log of the formations similar to that shown at **17** in FIG. 2A in addition to a conventional log of the location of the casing collars **93, 94**. The log obtained with this radioactivity device **89** is correlatable to the radioactivity logs **17, 18** obtained before the casing was set and, therefore, the position of the collars **93, 94**, as well as the particular location of the perforating apparatus **90** in the cased well, relative to the formations is easily determined. By utilizing such correlation, the tool **88** may be accurately positioned adjacent the collar **93** nearest to the formation of interest where the perforations are to be made. Then, using this collar **93** as a reference point, the perforating tool may be accurately positioned adjacent the formations of interest and operated in the well-known manner to produce perforations **95, 96** through the casing **85** into the formations.

It has heretofore been common practice to correlate formation logs obtained by conventional wireline logging instruments to the particular number of joints of drill pipe required to position a well tool adjacent a particular formation by calculating the amount of elongation or "stretch" of both the logging instrument's suspension cable and that of the assembled drill string. This practice involves first calculating the amount of stretch of the suspension cable to determine the depth of a particular formation and then calculating the amount of stretch of the drill string supporting a well tool to determine the number of joints of drill pipe required to position the tool adjacent that formation. Those skilled in the art realize, however, that such determinations can be subject to appreciable errors particularly when the formation of interest is several thousands of feet below the surface.

Using apparatus of the present invention, however, it will be appreciated that formations can be located and the required number of drill string joints can be easily and precisely determined to enable well tools to be accurately positioned relative to any particular formation in subsequent operations. Inasmuch as the apparatus of the present invention is suspended from a drill string, it will be understood that but for the inconsequential differences in weights between the testing apparatus and subsequently-used well tools, the drill string will be stretched the same amount during the testing operations as during all subsequent operations at the same depth. Thus, by correlating the relative location of particular zones along the span of the well bore to the number of joints in the drill string at the time the testing apparatus is adjacent each particular zone, it will be understood that whenever it is subsequently desired to position a well tool adjacent a particular formation, all that is necessary is to lower that tool on a string consisting of the same number of joints of drill pipe.

Such correlation can be easily made by logging the entire span of the well bore as the testing apparatus is either lowered into the well bore or removed therefrom. Since the logging recorder is running continuously, each time the drill string is halted to allow coupling or uncoupling of another joint, the recorder will produce a substantially unvarying record during the interval that the drill string is motionless. Accordingly, the logging records will consist of a series of varying logging measurements alternately interposed by a series of unvarying measurements indicative of each stop of the drill string as another joint is coupled or uncoupled. In subsequent operations, therefore, it will be necessary only to determine the actual number of joints in the string when the logging apparatus was adjacent any particular interval of formations, lower the well tool until that number of joints has been added to the string, and then position the well tool in accordance with the location of the formation relative to the point where the drill string had been halted to couple or uncouple a joint during the testing operations. As a further aid in determining the precise points on the logs when the drill string was halted, it is preferred to maintain a written time record of the operations; and since the recorder charts have a known time base, it is but a simple matter to verify each stopping point representation on the log by determining the particular times various chart readings were obtained.

The methods of the present invention require only that the pressure in the well bore be reduced below the natural formation pressure of the formation interval to be tested so that the connate formation fluids will flow into the borehole and drive the invaded filtrate out of the formation interval. Then, while only the connate fluids are in the formation interval, measurements are taken of formation properties which are altered or affected by the presence or absence of the filtrate invasion.

It will be appreciated, therefore, that there are several ways in which these steps can be performed. For example, a packer could be constructed and arranged to sealingly receive a drill string which could be reciprocated through a sleeve in the packer after it was positioned and set. The formation-logging instruments would be dependently attached to the drill string and a valve provided in the drill string. After positioning and setting the packer, the logging instruments would then be traversed along the full zone of investigation to obtain the first series of measurements. Then, the drill string valve would be opened to reduce the borehole pressure below the packer to allow the formation fluids to push the filtrate invasion out of the formation. The valve would be left open long enough to ensure that only the connate formation fluids remained in the formations. Then, after closing the valve and without releasing the packer, the logging instruments would be again traversed along the full formation interval to obtain the second series of measurements while the formation interval was still isolated. Here again, as previously described, it would not be necessary to perform the initial logging operations before reducing the pressure in the well bore. Other apparatus could also be used to perform the steps of the present invention.

It will be appreciated, therefore, that the apparatus previously described in detail is one that may also be used in the practice of the methods of the present invention. In using the apparatus illustrated in FIG. 3, the testing apparatus is lowered into well bore **10** (FIG. 1A) to a formation interval or zone to be investigated until bottom contact member **42** engages the bottom of borehole **10** (FIG. 1B). The combined weight of the testing apparatus and drill pipe **14** then forces bottom contact member **42** upwardly against the force of spring **52** which closes switch **43** thereby actuating relay assembly **41** to supply power from batteries **34** to data recorder **35**, gamma-ray logging instrument **36** and resistivity-logging circuits **37**. Compression of bottom member **42** simultaneously releases pad assembly **31** from its retracted position alongside logging instrument **28** thereby allowing the pad **38** to engage the surface of borehole **10**.

As seen in FIG. 1B, the testing apparatus is then pulled upwardly at a desired rate of speed to obtain a first series of logging data characteristic of the formations along the formation zone being investigated. The switch **43** opens when the testing apparatus is raised but relays **41** maintain a circuit between batteries **34** and the instrument's circuitry.

Upon reaching the upper limit of the formation interval being tested, the testing apparatus either may be halted and drillstem testing commenced or it may again be lowered to obtain additional series of logging data.

After a desired number of series of logging operations have been performed, the testing apparatus is positioned and packer 20 expanded to isolate the well bore 10 above the packer from the formation zone being investigated beneath the packer.

As seen in FIG. 1C, drillstem or flow testing is conducted in the conventional manner by manipulating drill pipe 14 to open and close the valve (not shown) contained within drillstem tester 19 so that any flowable fluids present in formations B, C below packer 20 will flow into ports 22 of perforated anchor 21 and be conducted via internal bore 23 upwardly through the drillstem tester and on into drill pipe 14.

As soon as the drillstem test has been completed, packer 20 is unseated to free the testing apparatus and the apparatus is again lowered to the bottom of the borehole 10 and then raised to obtain a second series of logging data as shown in FIG. 1D.

Here again, if so desired, although it is not necessary the testing apparatus may traverse the formation zone being investigated as many times as desired if additional series of logging data are wanted.

Whenever a sufficient number of logging operations has been conducted, the testing apparatus is then raised out of borehole 10 as seen in FIG. 1E and recorder 35 removed to permit recovery of the logs therein.

It will be appreciated from the foregoing that the present invention provides both novel methods and apparatus for practice of these methods to provide data which, when correlated and studied, will permit those skilled in the art to make reasonable predictions as to which particular strata of a particular formation interval investigated most likely are oil-bearing. These novel methods and apparatus permit such data to be obtained in a single operation without the necessity of making multiple round trips into and out of the well bore thereby saving considerable expense and downtime.

The novel methods may be practiced by the novel combination of various formation-logging instruments with a drillstem tester. Thus, a first series of formation logs can be taken along a particular formation followed by a drillstem test to drive filtrate out of the formations. The drillstem test is then immediately followed by one or more additional formation logs which will reflect changes in formation properties which are altered by the presence or absence of filtrate invasion. Comparison of these logs will afford a significant aid in the interpretation and evaluation of all of the logging data.

While particular embodiments of the present invention have been shown and described, it is apparent that changes and modifications may be made without departing from this invention in its broader aspects and, therefore, the aim in the appended claims is to cover all such changes and modifications as fall within the true spirit and scope of this invention.

What is claimed is:

1. A method for investigating subterranean permeable earth formations adjacent to a well bore containing fluids at a first pressure which have invaded the formations to displace natural formation fluids at a second lower pressure therein away from the well bore, comprising the steps of: reducing the pressure in the well bore adjacent to the formations to a pressure lower than the second pressure to produce invaded fluids and natural formation fluids from those of the formations that can be produced; and measuring a property or characteristic of the formations affected by the presence of produced fluids therein to determine whether the fluids adjacent to the well bore in any of the formations are substantially natural formation fluids.

2. A method for investigating an interval of subterranean permeable formations adjacent to a well bore containing fluids at a first pressure which have invaded the formation interval to displace natural formation fluids at a second lower pressure therein away from the well bore, comprising the steps of: isolating the portion of the well bore adjacent to the formation interval from the fluids in the remainder of the well bore; reducing the pressure in the isolated well bore portion to a pressure lower than the second pressure to produce invaded fluids and natural formation fluids from those formations in the isolated interval that can be produced; and measuring a property or characteristic of the formation interval affected by the presence of produced fluids therein to determine whether the fluids adjacent to the well bore in any of the formations in the interval are substantially natural formation fluids.

3. In a borehole containing a mudcake-forming liquid having a characteristic different from natural formation fluids and which has invaded formations to be investigated and formed a mudcake on the wall of the borehole adjacent thereto, the method of: reducing the pressure in the borehole opposite the invaded formations to produce invaded fluids and natural formation fluids from those formations that can be produced; raising the pressure in the borehole opposite the formations being investigated to re-invade the formations with such liquid and again displace natural formation fluids away from the borehole; and before any substantial re-invasion has occurred, measuring a property or characteristic of the re-invaded formations which varies as the re-entry of the liquid displaces natural formation fluids away from the borehole.

4. A method for investigation of subterranean earth formations traversed by a well bore using a testing assembly suspended from a string of pipe, said testing assembly including a formation-logging instrument connected to a testing device including packing-off means for isolating a portion of a well bore and valve means selectively operable between closed and open positions for controlling fluid communication between an isolated well bore portion and the string of pipe, comprising the steps of: setting the packing-off means within the well bore above a section of earth formations to be investigated for isolating the formation section from other portions of the well bore; opening the valve means for producing invaded and natural formation fluids from producible fluid-bearing formations along the formation section into the string of pipe; unseating the packing-off means; and before removing the testing assembly from the well bore, logging with the formation-logging instrument along the formation section for measuring a property characteristic of the presence of fluids in earth formations before removing the testing assembly from the well bore.

5. A method for investigation of subterranean earth formations traversed by a well bore using a testing assembly suspended from a string of pipe, said testing assembly including a formation-resistivity logging instrument connected to a testing device including packing-off means for isolating a portion of a well bore and valve means selectively operable between closed and open positions for controlling fluid communication between an isolated well bore portion and the string of pipe, comprising the steps of: setting the packing-off means within the well bore above a section of earth formations to be investigated for isolating the formation section from other portions of the well bore; opening the valve means for producing invaded and natural formation fluids from producible fluid-bearing formations along the formation section into the string of pipe; unseating the packing-off means; and measuring with the formation-resistivity instrument the electrical resistivity of the formation section for providing electrical signals representative of the electrical resistivity and recording the electrical signals so provided as a function of the depth of the testing assembly within the well bore before raising the testing assembly above the formation section.

6. A method for investigating subterranean permeable earth formations adjacent to a well bore containing fluids at a first higher pressure which have invaded the forma-

tions to displace natural formation fluids at a second lower pressure therein away from the well bore, comprising the steps of: reducing the pressure in the well bore adjacent to the formations to a pressure lower than the second pressure to produce invaded fluids and natural formation fluids from those of the formations that can be produced; measuring a property or characteristic of the formations affected by the presence of fluids therein before any substantial re-invasion of the fluids in the well bore is expected to re-occur; and after the fluids in the well bore are expected to have re-invaded the earth formations to again displace the natural formation fluids away from the well bore, remeasuring said property or characteristic of the formations to obtain differences between the measured and remeasured property or characteristic for determining whether natural formations fluids are produced from any of the formations when the pressure in the well bore was reduced.

7. A method for investigating an interval of subterranean permeable earth formations adjacent to a well bore containing fluids at a first higher pressure which have invaded the formation interval to displace natural formation fluids at a second lower pressure therein away from the well bore, comprising the steps of: isolating the portion of the well bore adjacent to the formation interval from communication with the fluids in the remainder of the well bore; reducing the pressure in the isolated well bore portion to a pressure lower than the second pressure to produce invaded fluids and natural formation fluids from those formations in the isolated interval that can be produced; re-establishing communication with the fluids in the remainder of the well bore to restore the pressure of the fluids in the well bore adjacent to the formation interval to the first pressure; measuring a property or characteristic of the formation interval affected by the presence of fluids therein before any substantial re-invasion of the fluids in the well bore is expected to re-occur; and after the fluids in the well bore are expected to have re-invaded the formation interval to again displace the natural formation fluids away from the well bore, remeasuring said property or characteristic of the formation interval to obtain differences between the measured and remeasured property or characteristic for determining whether natural formation fluids were produced from any of the formations in the interval when the pressure in the isolated well bore portion was reduced.

8. In a borehole containing a mudcake-forming liquid having a characteristic different from natural formation fluids and which has invaded earth formations to be investigated to form a mudcake on the wall of the borehole adjacent thereto, the method of: reducing the pressure in the borehole opposite the formations to be investigated to produce invaded fluids and natural formation fluids from those of the formations that can be produced; raising the pressure in the borehole opposite the formations being investigated to re-invade the producible formations with such liquid and again displace natural formation fluids therein away from the borehole; and before any substantial re-invasion is expected to have occurred, measuring a property or characteristic of the formations being investigated which varies as the entrance of the liquid again displaces natural formation fluids in any re-invaded formations away from the borehole; and after a substantial re-invasion is expected to have occurred, remeasuring said property or characteristic of the formations to obtain differences between said measured and remeasured property or characteristic for determining whether natural formation fluids were produced from any of the formations being investigated when the pressure in the borehole was reduced.

9. A method for investigation of subterranean earth formations invaded by fluids from within a well bore with a testing assembly suspended from a string of pipe and including a formation-logging instrument, packing-off means for isolating a portion of a well bore and valve means selectively operable between closed and open positions for controlling fluid communication between an isolated well bore portion and the string of pipe, comprising the steps of: setting the packing-off means within the well bore above a section of earth formations to be investigated for isolating the formation section from other portions of the well bore; opening the valve means for producing invaded and natural formation fluids from producible fluid-bearing formations within the formation section into the string of pipe; unseating the packing-off means; before any substantial re-invasion of fluids is expected to have occurred, logging with the formation-logging instrument the formation section for measuring a property characteristic of the presence of fluids in earth formations; and then, after a substantial re-invasion of the producible fluid-bearing formations is expected to have occurred, relogging with the formation-logging instrument the formation section for remeasuring such property before removing the testing assembly from the well bore.

10. A method for investigating subterranean permeable earth formations adjacent to a well bore containing fluids at a first higher pressure which have invaded the formations to displace natural formation fluids at a second lower pressure therein away from the well bore, comprising the steps of: measuring a property or characteristic of the formations affected by the presence of fluids therein; reducing the pressure in the well bore adjacent to the formations to a pressure lower than the second pressure to produce invaded fluids and natural formation fluids from those of the formations that can be produced; and remeasuring said property or characteristic of the formations before any substantial re-invasion of the fluids is expected to re-occur to obtain differences between said measured and remeasured property or characteristic for determining whether natural formation fluids were produced from any of the formations when the pressure in the well bore was reduced.

11. A method for investigating an interval of subterranean permeable earth formations adjacent to a well bore containing fluids at a first higher pressure which have invaded the formation interval to displace natural formation fluids at a second lower pressure therein away from the well bore, comprising the steps of: measuring a property or characteristic of the formation interval affected by the presence of fluids therein; isolating the portion of the well bore adjacent to the formation interval from communication with the fluids in the remainder of the well bore; reducing the pressure in the isolated well bore portion to a pressure lower than the second pressure to produce invaded fluids and natural formation fluids from those formations in the isolated formation interval that can be produced; re-established communication with the fluids in the remainder of the well bore to restore the pressure of the fluids in the well bore adjacent to the formation interval to the first pressure; and before any substantial re-invasion of the fluids in the well bore into the producible formations in the interval is expected to re-occur and again displace the natural formation fluids away from the well bore, remeasuring said property or characteristic of the formation interval to obtain differences between said measured and remeasured property or characteristic for determining whether natural formation fluids were produced from any of the formations in the isolated well bore portion was reduced.

12. A method for investigation of subterranean earth formations invaded by fluids from within a well bore with a testing assembly suspended from a string of pipe and including a formation-logging instrument, packing-off means for isolating a portion of a well bore, and valve means selectively operable between closed and open positions for controlling fluid communication between an isolated well bore portion and the string of pipe, comprising

the steps of: logging with the formation-logging instrument a section of earth formations to be investigated for measuring a property characteristic of the presence of fluids in earth formations; setting the packing-off means above the formation section being investigated for isolating the formation section from other portions of the well bore; opening the valve means for producing invaded and natural formation fluids from producible fluid-bearing formations within the formation section into the string of pipe; unseating the packing-off means; and before any substantial re-invasion of fluids into the producible formations is expected to occur, relogging with the formation-logging instrument the formation section for remeasuring such property.

13. A method for investigation of subterranean earth formations invaded by fluids within a well bore with a testing assembly suspended from a string of pipe and including a formation-resistivity measuring instrument, packing-off means for isolating a portion of a well bore, and valve means selectively operable between closed and open positions for controlling fluid communication between an isolated well bore portion and the string of pipe, comprising the steps of: measuring with the formation-resistivity instrument the electrical resistivity of a section of earth formations to be investigated for providing a first series of electrical signals representative of the measured electrical resistivity and recording the first series of electrical signals so provided as a function of the depth of the instrument within the well bore; setting the packing-off means above the formation section being investigated for isolating the formation section from other portions of the well bore; opening the valve means for producing invaded and natural formation fluids from producible fluid-bearing formations within the formation section into the string of pipe; unseating the packing-off means; and, before any substantial re-invasion of fluids is expected to have re-occurred, remeasuring with the formation-resistivity instrument the electrical resistivity of the formation section for providing a second series of electrical signals representative of the remeasured electrical resistivity and recording the second series of electrical signals so provided as a function of the depth of the testing assembly within the well bore before raising the testing assembly above the formation section.

14. The method of claim 13 further including the step of: correlating the first series of recorded signals with the second series of recorded signals to measure any differences therebetween for determining whether natural formation fluids were produced from any of the formations in the formation section when the valve means was opened.

15. A method for investigation of subterranean earth formations invaded by fluids within a well bore with a testing assembly suspended from a string of pipe and including a formation-resistivity measuring instrument, a radioactivity-measuring instrument, packing-off means for isolating a portion of a well bore, and valve means selectively operable between closed and open positions for controlling fluid communication between an isolated well bore portion and the string of pipe, comprising the steps of: measuring with the formation-resistivity and radioactivity-measuring instruments the electrical resistivity and radioactivity of a section of earth formations to be investigated for providing a first and second series of electrical signals respectively representative of the measured electrical resistivity and radioactivity and recording the first and second series of electrical signals so provided; setting the packing-off means above the formation section being investigated for isolating the formation section from other portions of the well bore; opening the valve means for producing invaded and natural formation fluids from producible fluid-bearing formations within the formation section into the string of pipe; unseating the packing-off means; and, before any substantial re-invasion of fluids is expected to have re-occurred, remeasuring with the formation-resistivity and radioactivity-measuring instruments the electrical resistivity and radioactivity of the formation section for providing a third and fourth series of electrical signals respectively representative of the remeasured electrical resistivity and radioactivity and recording the third and fourth series of electrical signals so provided before raising the testing assembly above the formation section.

16. A method for determining the location of a packer seat in an open well bore comprising the steps of: moving a string of tools suspended from a string of pipe and including a drillstem tester, a packer, and a logging device coupled to one another with the logging device being spaced at a known distance relative to the packer into a well bore, and, while moving the string of tools upwardly from the bottom of the well bore to a predetermined depth thereabove, recording as a function of distance from the bottom of the well bore a first series of measurements of at least one characteristic of the earth formations; lowering the lower end of the string of tools to the bottom of the well bore for setting the packer at a predetermined position in the well bore below said predetermined depth; operating the drillstem tester; unsetting the packer; again moving the string of tools upwardly to above the predetermined position and recording as a function of distance from the bottom of the well bore a second series of measurements of said one characteristic of the earth formations; and thereafter measuring the difference in indicated depths of reproduced measurements on the first and second log records to determine the actual distance from the bottom of the well bore to the point where the packer was set.

17. A method for completing wells comprising the steps of: passing into an open well bore on a drill string a first tool including a first radioactivity logging device and a tester with a packer means and a selectively-operable valve; logging with said first radioactivity logging device the earth formations traversed by the well bore to obtain a first log; testing at least some of the earth formations logged with the logging device by isolating a section of the well bore with the packer means and flowing fluids into the drill string by operating the tester valve; and subsequently, after casing of the well bore, passing a second tool into the cased well bore including a perforating means and a second radioactivity logging device; logging with said second radioactivity device the earth formations traversed by the casing to obtain a second log; and then positioning said perforating means adjacent such earth formations to be completed as determined by correlation of said first and second logs to one another; and thereafter operating said perforating apparatus.

18. A method for completing wells comprising the steps of: passing into an open well bore on a drill string a first tool including a first radioactivity logging device and a tester with a packer means and a selectively-operable valve; logging with said first radioactivity logging device the earth formations traversed by the well bore to obtain a first log; testing at least some of the earth formations logged with the logging device by isolating a section of the well bore with the packer means and flowing fluids into the drill string by operating the tester valve; and subsequently after casing of the well bore, passing a second tool into the cased well bore including a perforating means, a casing collar locator and a second radioactivity logging device; logging with said second radioactivity device the earth formations traversed by the casing to obtain a second log; and then positioning said perforating means at earth formations to be completed as determined by correlation of said first and second logs to one another and the location of a collar adjacent to the earth formations to be completed; and thereafter operating said perforating apparatus.

19. The method of positioning a well tool suspended from a string of separable sections of pipe at a selected

depth in a well bore adjacent a particular earth formation traversed by the well bore comprising the steps of: positioning apparatus including a logging instrument at the end of a string of separable sections of pipe at a first depth in the well bore; traversing the apparatus and pipe string in a particular direction along the well bore from said first depth to a second depth while operating the logging instrument to obtain varying representations characteristic of at least one property of the different earth formations adjacent to the well bore between said first and second depths; halting the apparatus and pipe string at said second depth to vary the length of the pipe string by coupling or uncoupling a separable section of pipe and to obtain substantially unvarying representations characteristic of said one property of the particular formation adjacent to the logging instrument at said second depth; alternately halting and traversing the apparatus and pipe string at successive depths in the same particular direction until the apparatus has reached a third depth in the well bore whereby the logging instrument provides a logging record having a first successive series of said varying representations for each traversal along the well bore of the apparatus alternating with a second successive series of unvarying representations for each halting of the apparatus in the well bore; removing the apparatus and pipe string; positioning a well tool on the pipe string at one of said first and third depths; and then positioning the well tool at a selected depth intermediate of said third and first depths by coupling or uncoupling to or from the pipe string a number of said separable pipe sections corresponding to removing the apparatus and pipe string; positioning a well tool on the pipe string at one of said first and third depths; the number of said unvarying representations on the logging record between said third depth and said selected depth.

**20.** The method of positioning a well tool suspended from a string of separable sections of pipe at a selected depth in a well bore adjacent a particular earth formation traversed by the well bore comprising the steps of: positioning apparatus including a radioactivity sensing and-recording instrument at the end of a string of separable sections of pipe at a first depth in the well bore; traversing the apparatus and pipe string in a particular direction along the well bore from said depth to a second depth while operating said radioactivity instrument to obtain of varying measurements or radioactivity levels of the different earth formations adjacent the well bore between said first and second depths; halting the pipe string at said second depth to vary the length of the pipe string by coupling or uncoupling a separable section of pipe and to obtain a second series of substantially unvarying measurements of the radioactivity level of the particular formation adjacent the radioactivity instrument at said second depth; alternately halting and traversing the apparatus and pipe string at successive depths in the same particular direction until the apparatus has reached a third depth in the well bore whereby the radioactivity instrument provides a logging record having a first successive series of said varying measurements for each traversal along the well bore of the apparatus alternating with said second successive series of unvarying measurements for each halting of the apparatus in the well bore; removing the apparatus and pipe string; positioning a well tool on the pipe string at one of said first and third depths; and subsequently positioning the well tool at a selected depth intermediate of said third and first depths by coupling or uncoupling to or from the pipe string a number of said separable pipe sections corresponding to the number of said unvarying measurements on the logging record between said third depth and said selected depth.

**21.** The method of determining the particular number of separable sections of pipe required to assemble a pipe string of sufficient length to position a well tool at a selected depth in a well bore relative to a datum point at the surface of the ground comprising the steps of: positioning a logging instrument at the end of a string of separable sections of pipe at a first depth lower than said selected depth; retrieving said string while logging and successively stopping said string whenever a separable section reaches said datum point to obtain a logging record characteristic of at least one property of the earth formations adjacent said well bore from said first depth to at least a second depth above said selected depth, said logging record being periodically interrupted by successive substantially unvarying representations corresponding to the formations adjacent each position where said instrument was successively stopped; then determining from said successive unvarying representations on said logging record the particular number of separable sections in the pipe string whenever said logging instrument passed said selected depth; and subsequently suspending a well tool on a string of pipe consisting of that particular number of separable sections to position said well tool at said selected depth.

**22.** The method of positioning a well tool suspended from a string of pipe at a particular depth including the steps of: lowering from a datum point at the earth's surface an apparatus including a logging instrument in a string of pipe to a given depth in a well bore where said string of pipe is comprised of separable sections and said logging instrument will provide a log of earth formations while moving with said string of pipe and distinctive indications whenever the string of pipe is halted to uncouple such sections of pipe at the earth's surface; retrieving said apparatus while said logging instrument is operating by successively uncoupling such sections of pipe at the earth's surface; and then positioning a well tool at a particular depth in the well bore relative to said given depth by reassembling a string of pipe comprising a number of said separable sections corresponding to the number of said distinctive indications between said datum point and said particular depth as determined from said log.

**23.** Apparatus adapted for passage through a well bore for evaluating fluid-production capabilities of subterranean earth formations traversed by the well bore comprised of: a flow-controlling device adapted for coupling to a string of drill pipe and having packer means for packing-off between said device and the periphery of the well bore for isolating a portion of the well bore from the rest of the well bore, said flow-controlling device including a fluid passage through said pack-off means for communicating an isolated well bore portion with a drill pipe, and valve means for selectively controlling fluid communication through said passage; and a formation-logging instrument coupled to said flow-controlling device and having means for detecting a property characteristic of the presence of fluids within earth formations for determining the effect of fluid production from earth formations.

**24.** Apparatus adapted for passage through a well bore for evaluating fluid-production capabilities of subterranean earth formations traversed by the well bore comprised of: a flow-controlling device adapted for coupling to a string of drill pipe and having packer means for packing-off between said device and the periphery of the well bore for isolating a portion of the well bore from the rest of the well bore, said flow-controlling device including a fluid passage through said pack-off means for communicating an isolated well bore portion with a drill pipe, and valve means for selectively controlling fluid communication through said passage; a formation-logging instrument coupled to said flow-controlling device and having electrical sensing means for detecting a property characteristic of the presence of fluids within earth formations; and power source means connected to said electrical means.

**25.** Apparatus adapted for passage through a well bore for evaluating fluid-production capabilities of subterranean earth formations traversed by the well bore comprised of: a flow-controlling device adapted for coupling to a string of drill pipe and having packer means for packing-off between said device and the periphery of the well bore for

isolating a portion of the well bore from the rest of the well bore, said flow-controlling device including a fluid passage through said pack-off means for communicating an isolated well bore portion with a drill pipe, and valve means for selectively controlling fluid communication through said passage; and a formation-logging instrument coupled to said flow-controlling device and having electrical means for sensing a detectable property characteristic of the presence of fluids within earth formations and providing an electrical signal representative of such detected property, recording means for registering such electrical signals, and power source means connected to said electrical sensing means, said sensing means, recording means and power source means being completely contained in said formation-logging instrument.

26. Apparatus adapted for passage through a well bore for evaluating fluid-production capabilities of subterranean earth formations traversed by the well bore comprised of: a flow-controlling device adapted for coupling to a string of drill pipe and having packer means packing-off between said device and the periphery of the well bore for isolating a portion of the well bore from the rest of the well bore, said flow-controlling device including a fluid passage through said pack-off means for communicating an isolated well bore portion with a drill pipe, and valve means for selectively controlling fluid communication through said passage; a formation-logging instrument coupled to said flow-controlling device and having first electrical sensing means for detecting a property characteristic of the presence of fluids within earth formations, and second electrical sensing means for detecting the emission of radioactive gamma rays from earth formations; and power source means connected to said first and second electrical sensing means.

27. Apparatus adapted for passage through a well bore for evaluating fluid-production capabilities of subterranean earth formations traversed by the well bore comprised of: a flow-controlling device adapted for coupling to a string of drill pipe and having packer means for packing-off between said device and the periphery of the well bore for isolating a portion of the well bore from the rest of the well bore, said flow-controlling device including a fluid passage through said pack-off means for communicating an isolated well bore portion with a drill pipe, and valve means for selectively controlling fluid communication through said passage; a formation-logging instrument coupled to said flow-controlling device and having first electrical means for sensing a detectable property characteristic of the presence of fluids within earth formations and providing a first series of electrical signals representative of such detected property, second electrical means for sensing the emission of radioactive gamma rays from earth formations and providing a second series of electrical signals representative of such radioactivity, recording means for separately registering such series of electrical signals, and power source means; and switching means for selectively connecting said power source means to said electrical means.

28. Apparatus adapted for passage through a well bore for evaluating fluid-production capabilities of subterranean earth formations traversed by the well bore comprised of: a flow-controlling device adapted for coupling to a string of drill pipe and having packer means for packing-off between said device and the periphery of the well bore for isolating a portion of the well bore from the rest of the well bore, said flow-controlling device including a fluid passage through said pack-off means for communicating an isolated well bore portion with a drill pipe, and valve means for selectively controlling fluid communication through said passage; a formation-logging instrument coupled to said flow-controlling device and having electrical means for sensing electrical resistivity of earth formations; and a downhole, self-contained power source means connected to said electrical means.

29. Apparatus adapted for passage through a well bore for evaluating fluid-production capabilities of subterranean earth formations traversed by the well bore comprised of: a flow-controlling device adapted for coupling to a string of drill pipe and having packer means for packing-off between said device and the periphery of the well bore for isolating a portion of the well bore from the rest of the well bore, said flow-controlling device including a fluid passage through said pack-off means for communicating an isolated well bore portion with a drill pipe, and valve means for selectively controlling fluid communication through said passage; and a formation-logging instrument coupled to said flow-controlling device and having electrical means for sensing electrical resistivity of earth formations and providing a series of electrical signals representative of such electrical resistivity, recording means for registering such series of electrical signals, and power source means connected to said electrical means, said sensing means, recording means and power source means being completely contained in said formation-logging instrument.

30. Apparatus adapted for passage through a well bore for evaluating fluid-production capabilities of subterranean earth formations traversed by the well bore comprised of: a flow-controlling device adapted for coupling to a string of drill pipe and having packer means for packing-off between said device and the periphery of the well bore for isolating a portion of the well bore from the rest of the well bore, said flow-controlling device including a fluid passage through said pack-off means for communicating an isolated well bore portion with a drill pipe, and valve means for selectively controlling fluid communication through said passage; and a formation-logging instrument coupled to said flow-controlling device and having first electrical means for sensing electrical resistivity of earth formations, second electrical means for detecting the emission of radioactive gamma rays from earth formations, and power source means connected to said electrical means.

31. Apparatus adapted for passage through a well bore for evaluating fluid-production capabilities of subterranean earth formations traversed by the well bore comprised of: a flow-controlling device adapted for coupling to a string of drill pipe and having packer means for packing-off between said device and the periphery of the well bore for isolating a portion of the well bore from the rest of the well bore, said flow-controlling device including a fluid passage through said pack-off means for communicating an isolated well bore portion with a drill pipe, and valve means for selectively controlling fluid communication through said passage; a formation-logging instrument coupled to said flow-controlling device and having first electrical means for sensing electrical resistivity of earth formation and providing a first series of electrical signals representative of such electrical resistivity, second electrical means for sensing the emission of radioactive gamma rays from earth formations and providing a second series of electrical signals representative of such radioactivity, recording means for separately registering such series of electrical signals, and power source means; and switching means for electrically connecting said power source means to said electrical means in response to engagement of said switching means with a surface of a well bore.

32. Apparatus adapted for passage through a well bore for evaluating fluid-production capabilities of subterranean earth formations traversed by the well bore comprised of: a flow-controlling device adapted for coupling to a string of drill pipe and having packer means for packing-off between said device and the periphery of the well bore for isolating a portion of the well bore from the rest of the well bore, said flow-controlling device including a fluid passage through said pack-off means for communicating an isolated well bore portion with a drill pipe, and valve means for selectively controlling fluid communication through said passage; and a formation-

logging instrument coupled to said flow-controlling device and having electrical means for sensing electrical resistivity of earth formations.

33. Apparatus adapted for passage through a well bore for evaluating fluid-production capabilities of subterranean earth formations traversed by the well bore comprised of: a flow-controlling device adapted for coupling to a string of drill pipe and having packer means for packing-off between said device and the periphery of the well bore for isolating a portion of the well bore from the rest of the well bore, said flow-controlling device including a fluid passage through said pack-off means for communicating an isolated well bore portion with a drill pipe, and valve means for selectively controlling fluid communication through said passage; and a formation-logging instrument coupled to said flow-controlling device and having first electrical means for sensing a detectable property characteristic of the presence of fluids within earth formations and providing a first series of electrical signals representative of such detected property, second electrical means for sensing the emission of radioactive gamma rays from earth formations and providing a second series of electrical signals representative of such radioactivity, recording means for concurrently registering each of such series of electrical signals, power source means, and switching means for electrically connecting said power source means to said first and second electrical means upon engagement of said switching means with a surface of a well bore.

34. Apparatus adapted for passage through a well bore for evaluating fluid-production capabilities of subterranean earth formations traversed by the well bore comprised of: a flow-controlling device adapted for coupling to a string of drill pipe and having packer means for packing-off between said device and the periphery of the well bore for isolating a portion of the well bore from the rest of the well bore, said flow-controlling device including a fluid passage through said pack-off means for communicating an isolated well bore portion with a drill pipe, and valve means for selectively controlling fluid communication through said passage; and a formation-logging instrument coupled to said flow-controlling device and having first electrical means for sensing electrical resistivity of earth formations and providing a first series of electrical signals representative of such electrical resistivity, second electrical means for sensing the emission of radioactive gamma rays from earth formation and providing a second series of electrical signals representative of such radioactivity, recording means for concurrently registering each of such series of electrical signals, power source means, and switching means for electrically connecting said power source means to said first and second electrical means upon engagement of said switching means with a surface of a well bore.

**References Cited by the Examiner**

UNITED STATES PATENTS

| | | | |
|---|---|---|---|
| 2,156,052 | 4/1939 | Cooper | 73—152 X |
| 2,320,863 | 6/1943 | Green | 200—61.42 X |
| 2,320,890 | 6/1943 | Russell | 166—4 |
| 2,459,499 | 1/1949 | Castel | 200—61.42 X |
| 2,320,890 | 6/1943 | Russell | 166—4 |
| 2,650,067 | 8/1953 | Martin | 73—152 X |
| 3,038,333 | 6/1962 | Allen et al. | 73—155 |

RICHARD C. QUEISSER, *Primary Examiner.*

J. W. MYRACLE, *Assistant Examiner.*