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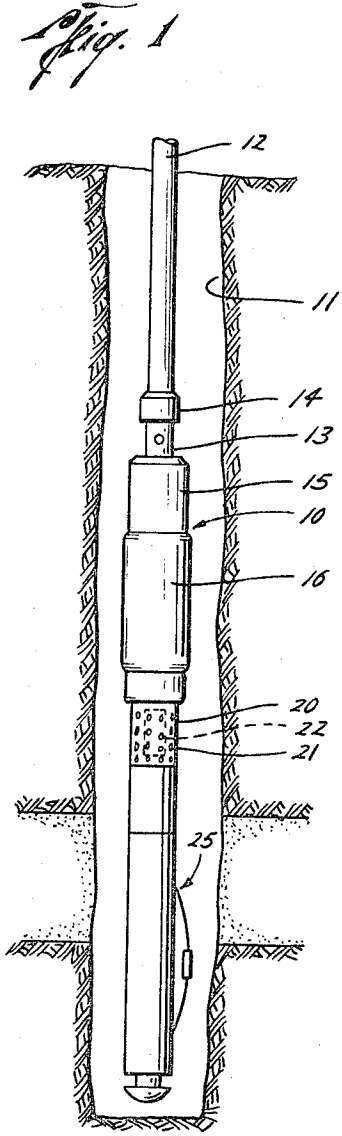
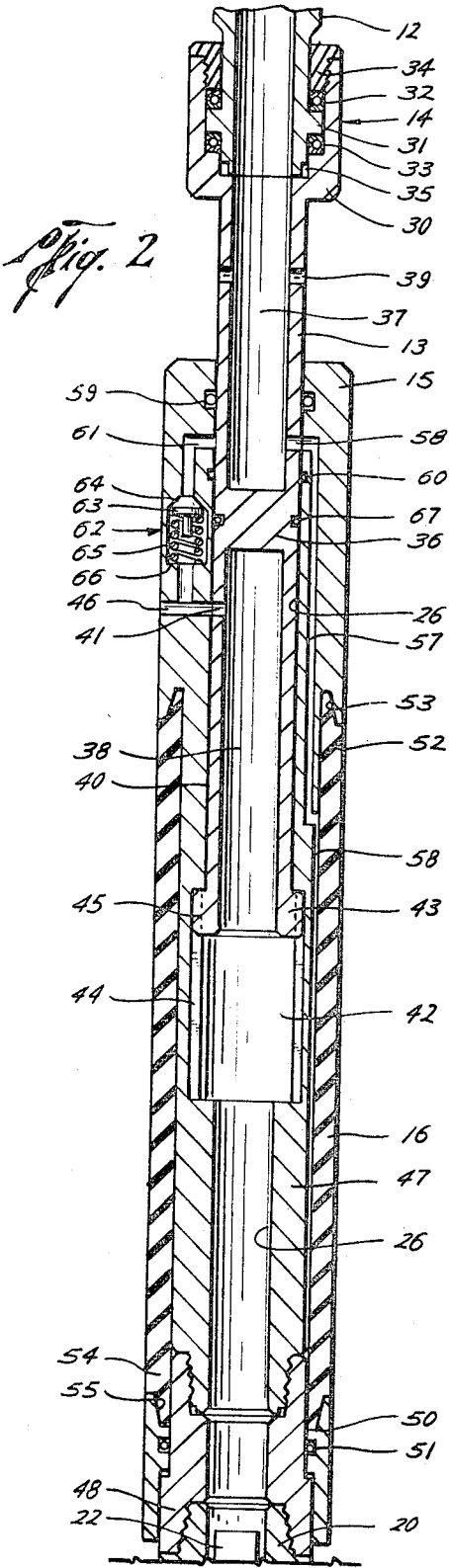
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METHODS AND APPARATUS FOR SOFT SAND TESTING

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Sheet 1 of 2



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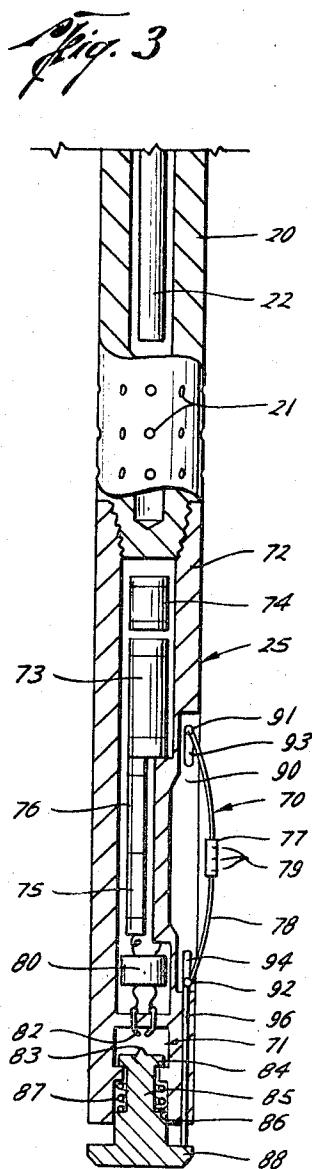
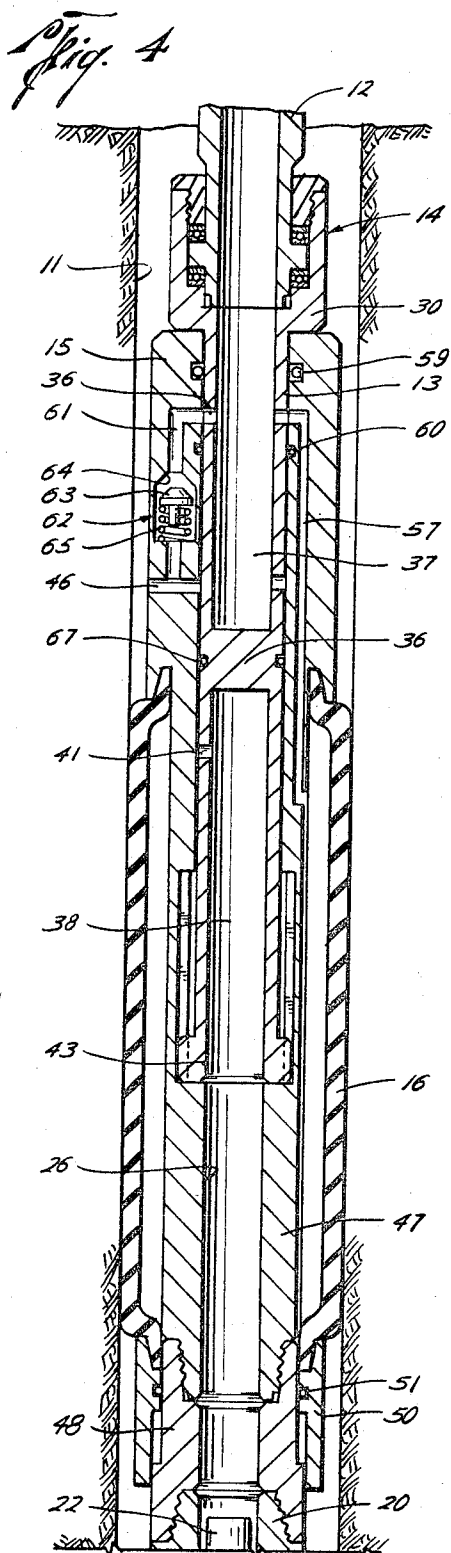
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METHODS AND APPARATUS FOR SOFT SAND TESTING

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17 Claims

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ABSTRACT OF THE DISCLOSURE

Methods and apparatus for testing soft sand earth formations traversed by a fluid filled well bore are described. According to the methods, a packer on a pipe string is lowered into the well bore and the packer is expanded to isolate a formation zone, the zone being also isolated from the pipe string. Fluid pressure in the isolated zone is then measured over a period of time. Further, fluid circulation can be maintained above the packer, and the pipe string can be kept in motion. The apparatus includes an inflatable packer which can be expanded by fluid pressure in the pipe string, the packer having a blocked bore. Pressure recorders are provided to measure pressures in the zone which is completely isolated by the packer and the blocked bore during the test.

This invention relates to methods and apparatus for obtaining valuable data concerning subterranean well formations having poor structural characteristics and/or where the well bore is deviated from the vertical, to an extent that ordinary drill stem testing is undesirable.

In geographical areas where it is common to drill well bores into unconsolidated sand or heaving shale formations, for example, the Gulf Coast area of the United States, ordinary drill stem testing has never been popular because of the substantial risk of losing the tool in the well bore. For example, if the hydrostatic pressure of the fluids in an isolated zone is greatly reduced below the formation fluid pressure, the unconsolidated sand or shale tends to dump out into the well bore and fill either a cased or an open hole.

In geographical areas where it is common to drill excessively deviated well bores through permeable formation zones, differential pressure sticking of the drill pipe can occur. Moreover, there can be a combination of these circumstances where excessively deviated well bores are drilled into unconsolidated sand or heaving shale formations.

With proper hydrostatic pressure control, these formations can be logged with conventional wireline electrical logging tools to obtain lithography, formation density and porosity. However, a good measurement of the actual hydraulic pressure within the formation is not obtained, a measurement which is highly useful in the analysis of a formation's commercial prospects.

It is accordingly an object of the present invention to provide new and improved methods and apparatus for gathering well data concerning the above-mentioned types of formations without the risk of losing the testing tools and wherein the fluid pressures within such formation can be determined.

In general, the method of the present invention includes the steps of lowering a well packer on a pipe string into a well bore which traverses the earth formation to be tested, expanding the packer to isolate a zone of the well bore from fluids in the remainder of the well bore, measuring the pressures of fluids in the isolated zone during a time interval, and maintaining circulation of fluids in the well bore during the test. Additionally, the method of the present invention may include the step of

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moving the pipe string while the zone is isolated and the further step of measuring at least one physical characteristic of the earth formation being tested after the pressures of fluids in the isolated zone has been measured.

The apparatus of the present invention is generally described as comprising logging means for sensing, measuring and recording properties of the well formation. Tubular members having a closed bore are connected to said logging means and the tubular members are rotatively coupled to a pipe string extending upwardly to the earth's surface. Inflatable packing means on the tubular members is expandable in response to fluid pressure for isolating a selected formation interval, the pressure acting through an inflation passage which communicates the packing means with the interior of the pipe string. Means are provided for recording fluid pressure changes of the fluids in the well bore adjacent the isolated formation interval and a circulation passage means in the members permits circulation of fluids through the pipe string and well annulus while the packing means is expanded.

A full disclosure of an embodiment of the invention follows to facilitate a full understanding of the concepts involved. This disclosure includes the attached drawings in which:

FIGURE 1 is an elevational view of one embodiment of the invention shown in connection with the well bore;

FIGURE 2 is an enlarged longitudinal sectional view of the upper portion of the apparatus shown in FIGURE 1;

FIGURE 3 is longitudinal partial sectional view of the lower portion of the apparatus shown in FIGURE 1, FIGURE 3 forming a lower confirmation of FIGURE 2; and

FIGURE 4 is a sectional view of the upper portion of the apparatus shown in FIGURE 2 with parts of the apparatus in operative positions to test a formation zone.

Referring initially to FIGURE 1, the apparatus of the present invention is generally designated by the numeral 10 and is shown suspended within a well conduit 11 on a running-in string 12 which extends upwardly to the earth's surface. The apparatus 10 includes an inner tubular member 13 connected at its upper end by a coupling 14 to the running-in string 12 and telescopically disposed within an outer tubular member 15 for movement between the expanded and contracted relative positions. An inflatable packer element 16 is mounted on the members 13, 15 and is adapted for lateral expansion into sealing engagement with the wall of the well conduit 11 to isolate a selected formation zone.

A section of perforated anchor pipe 20 is connected to the lower end of the outer tubular member 15 and has a plurality of ports 21 for communicating the bore of the anchor pipe 20 with the well fluids in the annular space below the packer element 16. Contained within the bore of the anchor pipe 20 is at least one pressure recorder 22 for obtaining a permanent record of fluid pressure changes versus elapsed time in a conventional manner.

An electrical logging device 25 forms a lower portion of the apparatus 10 and contains suitable instrumentation, to be discussed in more detail hereafter, for sensing and recording indicia from which well parameters such as lithography, density and porosity can be determined.

Referring now to FIGURE 2, the inner tubular member 13 is slidably received within the bore 26 of the outer tubular member 15 for telescoping movement therein. The inner member has a box portion 30 at its upper end which is connected to the lower end of the running-in string 12 by a rotatable coupling 14. An outwardly extending flange 31 on the running-in string 12 is received between antifriction bearings 32, 33 which are confined

within the box portion 30 by a threaded ring 34. A suitable seal element 35 is positioned at the lower end of the string 12 between it and the box portion 30. In this manner, the running-in string 12 is rotatable relative to the tubular members 13, 15 while the coupling 14 provides a fluid-tight connection therebetween.

A partition or barrier 36 segregates the interior of the inner member into upper and lower bores 37, 38, respectively, and functions to block fluid communication therebetween, thereby prohibiting any fluid flow longitudinally through the tubular members. A plurality of ports or passageways 39 are provided in the inner tubular member 13 intermediate the box portion 30 and the barrier 36 and are spaced above the upper end of the outer tubular member 15 when the members are expanded as shown in FIGURE 2 to establish fluid communication between the interior of the running-in string 12 and the well annulus above the packer element 16. A lower portion 40 of the inner member 13 extends downwardly below the barrier 36 and a bypass port 41 extends through the wall of the lower portion 40 below the barrier.

The bore 26 of the outer member 15 is enlarged intermediate the ends thereof to provide a chamber section 42 which slidably receives an outwardly extending flange 43 at the lower end of the inner member 13. Interengaging splines 44, 45 on the wall of the chamber section 42 and the outer periphery of the flange 43, respectively, corotatively secure the inner and outer members together. A bypass passageway 46 extends laterally in the wall of the outer member 15 and registers with the inner member bypass port 41 when the members are expanded to permit well fluids to bypass through the members and around the packer element 16 via the anchor pipe perforations 21, the bore 26 of the outer member 15, the lower bore 38 of the inner member 13 and the bypass ports or passageways 41, 46.

The outer member 15 has a tubular section 47 which extends downwardly from the chamber section 42 and is threadedly connected to its lower end to an annular sub which forms the lower portion 48 of the outer member 15. The lower portion has stepped outer surfaces which slidably receive a packer return sleeve 50 and suitable seal elements 51 fluidly seal between the sleeve 50 and the outer surfaces of the lower portion 48.

The packer element 16, in the form of an annular elastomer sleeve, is mounted around the outer member 15 with its upper end 52 secured and sealed within a recess 53 in the outer member and its lower end 54 secured and sealed within a recess 55 in the return sleeve 50. The packer element 16 is adapted for lateral expansion responsive to fluid pressures exerted on the internal surfaces thereof into sealing engagement with the wall of the well conduit 11.

An inflation passageway 57 in the outer member 15 provides fluid communication to the space 58 between the packer element 16 and the outer member 15 and opens into the bore 26 of the outer member between upper and lower spaced seal elements 59, 60 between the members. The inflation passageway 57 registers with a port 58 in the inner member above the barrier 36 when the members are expanded so that fluid pressures within and without the packer element can equalize during run-in. Alternatively, the inflation passageway 57 registers with one of the ports 39 in the inner member 13 when the members are contracted (FIG. 4) whereby fluid pressure applied to the fluids within the running-in string 12 will act to inflate the packer element 16. As the packer element 16 is inflated, the sleeve 50 can move longitudinally on the lower portion 48 to accommodate changes in length of the packer element.

A circulation passageway 61 is also provided in the outer member 15 for circulation of fluids between the interior of the running-in string 12 and the well annulus above the packer element 16 when the members 13, 15 are in their contracted relative position. The passageway

61 opens at its upper end into the bore 26 of the outer member between the longitudinally spaced seal elements 59, 60 and the lower end of the passageway 61 intersects the lateral bypass passageway 46. In the contracted position, the circulation passageway 61 registers with one of the ports 39 in the inner member 13 to place the passageway in communication with the interior of the running-in string 12 via the upper bore 37 of the inner member.

A unidirectional flow valve 62 is positioned within the circulation passageway 61, the valve including a valve element 63 which is pressed upwardly against a companion seat 64 by a compression spring 65 seated between a shoulder 66 in the passageway and the lower face of the valve member. The compression spring 65 exerts a predetermined upward force on the valve element 63 so that a known fluid pressure is required to move the valve element downwardly away from its seat to open the passageway 61 to fluid flow. It is preferable that the pressure required to open the valve 62 is at least as great as the pressure required to fully inflate the packer element 16 for assurance that the packer element is maintained in sealing engagement with the wall of the well conduit 11 when the valve opens.

As shown in FIGURES 2 and 3, the perforated anchor pipe 20 is dependently secured to the lower portion 48 of the outer tubular member 15 and has a plurality of lateral ports 21 arranged to communicate the interior of the anchor pipe with the well annulus below the packer member 16. Suitably secured within the anchor pipe 20 is one or more pressure recorders 22 of the type shown in U.S. Patent No. 2,816,440 for recording pressure changes of the well fluids below the packer element as a function of elapsed time.

Dependently coupled to the lower end of the anchor pipe 20 is the formation logging instrument 25 on which is secured a pad assembly 70 and a switch assembly 71. The more specific details of the logging instrument form no part of the present invention and are fully set forth in application Ser. No. 327,947 of Maurice P. Lebourg, filed Dec. 4, 1963, now U.S. Patent No. 3,306,102. Briefly described, the formation logging instrument includes an outer housing 72, preferably made of metal, which encloses batteries 73, a data recorder 74 and any one or more of conventional logging instruments such as, for example, a gamma ray logging instrument 75 and electrical resistivity measuring circuits 76 in separate compartments. The logging instruments and circuits each detect particular properties which are characteristic of the fluids within the formations adjacent the logging instruments and convert the detected characteristics into electrical signals representative thereof. The electrical signals are then recorded on a data recorder 74 which may be any conventional machine normally used in the art. A typical resistivity measuring apparatus is shown in U.S. Patent No. 2,712,629, and a typical gamma ray logging apparatus is shown in U.S. Patent No. 2,349,225.

The pad assembly 70 includes an insulated wall engaging pad 77 attached to the housing 72 by a strong bow-spring 78 which can be coated with an electrical insulating material such as epoxy resin. A plurality of spaced apart electrodes 79 are embedded in the outer surface of the pad 77, the electrodes being either flush with the face of the pad or slightly recessed therein.

At the lower end of the logging instrument 25 is the switching assembly 71 to selectively turn on electrical power to the various components within the logging instrument. The switching assembly 71 includes a relay assembly 80 which can be a conventionally arranged holding circuit for maintaining power to the components after momentary actuation of the switching assembly 71.

The switching assembly includes resilient electrical contacts 82 spaced apart from one another in such a manner that a male conductor 83 will bridge the gap between the contacts 82 whenever the contact members and conductor are engaged. Of course, the male conductor and the resil-

ient contacts are electrically insulated from the housing 62 by suitable means (not shown).

The male conductor 83 is centrally located on top of an enlarged portion 84 of a cylindrical plunger member 85 which is slidably received within a bore 86 at the lower end of the housing 72. A compression spring 87 encircles the plunger and presses the plunger downwardly so that the male conductor 83 is normally spaced away from the resilient contacts 82. A lower portion of the plunger member 85 is enlarged to provide a bottom contact member 88 and it will be appreciated that on upward force on the bottom contact member 88 sufficient to overcome the force of the spring 87 will move the plunger member 85 upwardly and the male conductor 83 into engagement with the resilient contacts 82.

Although it is not necessary, it is preferred that the pad assembly 70 be in a retracted position within a housing recess 90 for its protection when lowering the apparatus into the well bore 11. For this purpose, the ends of the bow-spring 78 are fixedly attached to hinge members 91, 92 which are slidably received in longitudinal slots 93, 94 cut in the sides at both ends of the recess 90. When the pad is retracted, the lower hinge member 92 is held at the bottom of slots 94 by a shear pin (not shown) which is strong enough to constrain the bow-spring 78 in its extended or retracted position. An actuating rod 96 is received within a longitudinal bore which extends through a portion of the housing 72 from the lower end of the recess 90 to the lower end of the switch assembly 71. The upper end of the rod 96 contacts the lower hinge member 92 and the lower end rests freely on the upper side of the bottom contact member 88. Thus, when the bottom contact member is moved upwardly by a predetermined force, the thrust rod will move upwardly to shear the pin 95. Failure of the shear pin frees the lower hinge member and permits it to move upwardly in the slots 94 as the bow-spring 78 moves the pad member 77 outwardly into engagement with the well bore wall.

The invention is operated as follows. The apparatus 10, assembled as shown in the drawings, is lowered into the well bore 11 to a formation zone or interval to be investigated. While lowering, the inner and outer members 13, 15 are in their expanded position with the ports 39 communicating the running-in string 12 with well annulus above the packing element 16 and the bypass passageways 41, 46 are in registry. As the apparatus moves downwardly, fluids in the well bore can bypass the packer element 16 both around the exterior thereof and through the apparatus via the bypass passageways 41, 46 as previously described. Also, well fluids can enter the running-in string 12 through the ports 39 to fill the string as the apparatus is lowered.

When the bottom of the well bore is reached, the bottom contact member 88 engages the bottom of the bore hole and the weight of the apparatus 10 forces the bottom contact member 88 upwardly, thereby closing the switch 71 to activate the relay assembly 80 in preparation for supplying power from the batteries 73 to the data recorder 74, the gamma ray logging instrument 75 and the resistivity logging circuits 76. Upward movement of the bottom contact member also serves to release the pad assembly 70 from its retracted position, thereby permitting the pad 77 to shift outwardly into engagement with the well bore wall.

With the lower part of the apparatus 10 and thus the outer member 15 resting on bottom, further downward movement of the running-in string 12 serves to telescope the inner and outer members 13, 15 to their contracted position, shown in FIG. 4, wherein the inner member ports 39 register with the circulation passageway 61 and the inflation passageway 57 in the outer member 15. The packer bypass passageways 41, 46 are sealed off from one another by a seal element 67 and the barrier 36 in the inner member 13 continues to prohibit fluid flow longitudinally through the members.

Pump pressure is then applied at the earth's surface to the fluids within the running-in string 12, the pressure acting via the inflation passageway 57 to expand the packer element 16 into sealing engagement with the well bore wall. This pressure also acts via the passageway 61 against the valve element 62 but the upward force of the spring 65 resists movement of the valve element until the unit pressure thereon exceeds the unit pressure required to fully expand the packer element 16, which can be, for example, 500 p.s.i.

When the packer element 16 is fully expanded to isolate the formation interval, further increased pump pressure acts to open the valve 62 and thereby communicate the running-in string with the well annulus just above the packer element so that continuous mud circulation can be maintained. The running-in string 12 can be kept in rotative motion due to the coupling 14 between the string and the inner member 13 to combat differential pressure sticking.

Once the packer element 16 is inflated, the fluid pressure in the well annulus therebelow will increase slightly to reflect the setting of the packer element and the trapping of the fluid at its hydrostatic pressure. Thereafter the space below the packer element is isolated so that "pressure decay" can occur, e.g., the pressure of fluids in the well bore adjacent the isolated interval will decrease as fluid in the well bore continues to enter the formation, thus causing the well bore fluid pressure to gradually approach or equalize to the lower pressure of the fluids in the formation. The pressure decay function can be used in a manner similar to the pressure build-up function measured in ordinary drill stem testing to accurately determine the true or "virgin" formation fluid pressure in a known manner. Moreover, the pressure decay measurements can be utilized in the detection of formation anomalies such as faults and fluid contact points.

Hence, over a period of time, the pressure of fluids in the formation is measured and recorded on the pressure recorder 22, yet the pressure within the well bore adjacent the formation is never less than the formation fluid pressure, thus preserving the integrity of the formation's structural characteristics and preventing dumping or heaving of formation material into the well bore. After a sufficient period of time to measure the pressure decay function, the running-in string 12 is picked up to move the members 13, 15 to their expanded position. This movement serves to open the bypass passages 41, 46 to equalize pressures across the packer element. Then the packer element 16 is deflated for upward movement of the apparatus within the well bore.

After deflating the packer element, the testing apparatus is pulled upwardly at a desired rate of speed to obtain a series of logging data characteristic of the formations along the test interval. As the bottom contact member 88 lifts off bottom, the plunger member 85 is pressed downwardly by the spring 87 and the switch 71 opens, but the relays 80 close a circuit between the batteries 73 and the various instrument circuitry. If desired, the apparatus can be lowered again to obtain additional series of logging data.

It will now be apparent that new and improved methods and apparatus have been disclosed for gathering well data such as lithography, density and porosity of a subterranean well formation as well as the true hydraulic pressures of fluids within the formation. The apparatus is constructed and arranged in a manner whereby lost tool risks are minimal. Since certain changes may be made in the embodiment disclosed without departing from the inventive concept, it is intended that all matter contained in the foregoing description or shown in the attached drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. Apparatus for use in testing earth formations traversed by a well bore comprising: a body carrying in-

flatable packer means and adapted for connection with a string of pipe extending to the earth's surface, said packer means being expandable in response to fluid pressure in the pipe string for isolating a selected formation interval; inflation passage means in said body for communicating said packer means with the interior of the pipe string, said body having a closed off bore to prevent communication between the formation interval and the pipe string at all times during testing; and recorder means carried by said body for recording changes in fluid pressure below said packer means and said closed bore to obtain a record thereof as a function of lapsed time after the packer means isolates the formation interval, thereby obtaining a record of changing pressures as fluid pressures in the well bore below said packer means and said closed bore tend to equalize with fluid pressures in the isolated formation interval.

2. Apparatus as recited in claim 1 further including passage means in said body for circulating fluids through the pipe string and the well annulus above said isolated formation interval while said recording means obtains a pressure record.

3. Apparatus as recited in claim 2 further including pressure responsive means in said circulation passage means operable to open said circulation passage means at a pressure at least as great as the pressure required to fully expand said packer means.

4. Apparatus as recited in claim 1 further including coupling means on said body for connecting said body to the pipe string, said coupling means including relatively rotatable parts whereby the pipe string can be rotated relative to the body while said recorder means obtains a pressure record.

5. Apparatus as recited in claim 1 further including bypass passage means in said body permitting fluid passage between the well annulus spaces above and below said packer means; and means for selectively closing said bypass passage means.

6. Apparatus for use in testing and logging earth formations traversed by a well bore comprising: logging means for sensing, measuring, and recording characteristic properties of a well formation; tubular members connected to said logging means, said members having a closed bore; means for coupling said tubular members to a pipe string extending upward to the earth's surface; inflatable packer means on said members expandable in response to fluid pressure for isolating a selected formation zone, said closed bore at all times during a test preventing fluid communication between the pipe string and the isolated formation zone; inflation passage means communicating said packer means with the interior of the pipe string; and means for recording changes in fluid pressure below said packer means and said closed bore to obtain a record thereof as a function of lapsed time after the packer means isolates the formation zone.

7. Apparatus as recited in claim 6 further including passage means in said members for circulating fluids between the pipe string and the well annulus above the packer means while said recording means obtains a pressure record.

8. Apparatus as recited in claim 7 further including a pressure responsive valve means in said circulation passage means operable to open said circulation passage means at a pressure at least as great as the pressure required to fully expand said packer means.

9. Apparatus as recited in claim 6 wherein said coupling means includes relatively rotatable parts whereby the pipe string can be placed in motion relative to said tubular members.

10. Apparatus as recited in claim 6 further including bypass passage means permitting fluid passage between

the well annulus spaces above and below said packer means; and means for selectively closing said bypass passage means.

11. A well tool comprising: inner and outer tubular members telescopically movable between expanded and contracted relative positions, said members having means blocking fluid flow through therethrough; means for coupling said members to a pipe string extending upwardly to the earth's surface; inflatable packer means on said members expandable in response to fluid pressure for isolating a selected formation interval; inflation passage means communicating said packer means with the pipe string whereby fluid pressure applied through the pipe string is effective to inflate said packer means; passage means in said members cooperable in at least one of said relative positions for communicating the pipe string with the well annulus above said packer means so that fluids can be circulated therethrough; and means for recording fluid pressures below said packer means and said blocking means to obtain a record of said pressures after said packer means isolates the formation interval.

12. Apparatus as recited in claim 11 wherein said coupling means includes relatively movable parts whereby the pipe string can be moved relative to said tubular members while said packer means is expanded.

13. Apparatus as recited in claim 11 further including bypass passage means permitting fluid passage between the annulus spaces above and below said packer means; and means for selective opening and closing said bypass passage means.

14. Apparatus as recited in claim 11 further including pressure responsive valve means in said circulation passage means operable to open said circulation passage means at a pressure at least as great as the pressure required to inflate said packer means.

15. A method of testing subterranean earth formations traversed by a fluid filled well bore, comprising the steps of: lowering a well packer on a pipe string into the well bore; expanding the packer to isolate a zone of the well bore from fluids in the remainder of the well bores; maintaining the zone isolated from the interior of the pipe string during the test; measuring the pressure of fluids in the isolated zone during a time interval; and circulating fluids through the pipe string and the well annulus in the remainder of the well bore while the packer is expanded.

16. The method recited in claim 15 including the further step of: moving the pipe string while the packer is expanded.

17. The method recited in claim 15 including the further step of: measuring at least one physical property of the earth formation after the pressure of fluids in the isolated zone has been measured.

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