United States Patent [19]

Tanguy et al.

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[54] **METHODS AND APPARATUS FOR DETECTING THE ENTRY OF FORMATION GAS INTO A WELL BORE**

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[21] Appl. No.: **242,320**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 105,885, Jan. 12, 1971, abandoned.

[52] **U.S. Cl.** **73/153**

[51] **Int. Cl.** **E21b 47/10**

[58] **Field of Search**..... 73/151, 153, 155, 421.5 R; 166/264; 175/48, 317, 318, 321

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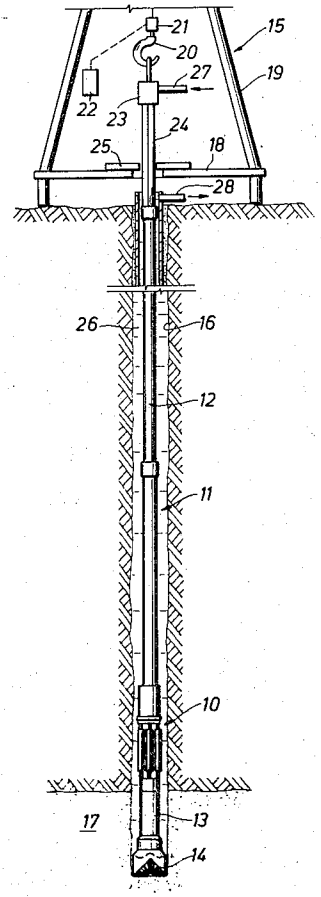
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[57] **ABSTRACT**

As a preferred mode for practicing the invention disclosed herein, a discrete sample of drilling mud from the borehole is periodically trapped within an expansible sampling chamber defined between a pair of telescoping members coupled to a drill string adjacent to the drill bit. By moving the drill string so as to expand the sampling chamber, the pressure of the entrapped sample is reduced to at least the saturation pressure of a gas-containing drilling mud at the borehole ambient temperature. By measuring the force required to expand the sampling chamber, the presence or absence of formation gas in the drilling fluid can be determined; and, if desired, these force measurements may be used to derive quantitative measurements which are representative of the percentage of gas entrained in the discrete sample. In the representative embodiments of the apparatus of the present invention disclosed herein, one or more unique sampling devices are arranged between the upper and lower telescoping members of a typical slip joint which is tandemly connected in the drill string preferably a short distance above the drill bit. Each of these fluid samplers includes telescoping piston and chamber members defining an enclosed sample chamber which is expanded in response to extension of the slip joint members. Valve means are cooperatively arranged with each of the sampling devices for admitting a predetermined volume of drilling mud into the sample chamber each time the slip joint is extended.

52 Claims, 17 Drawing Figures



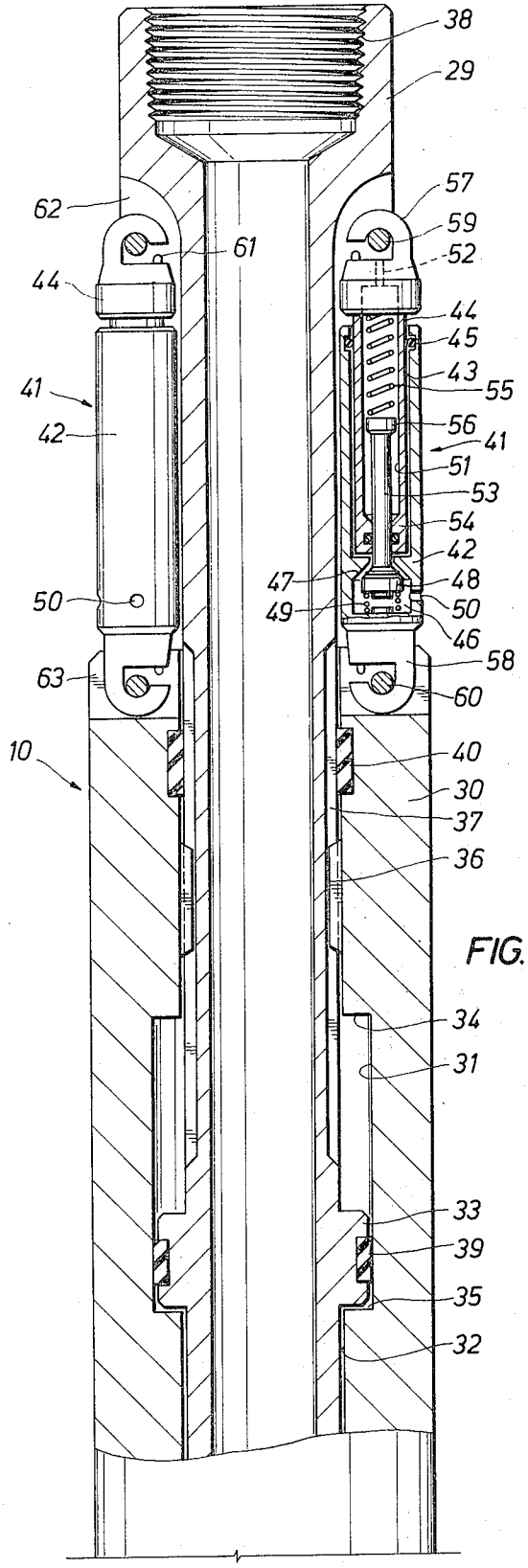


FIG. 2

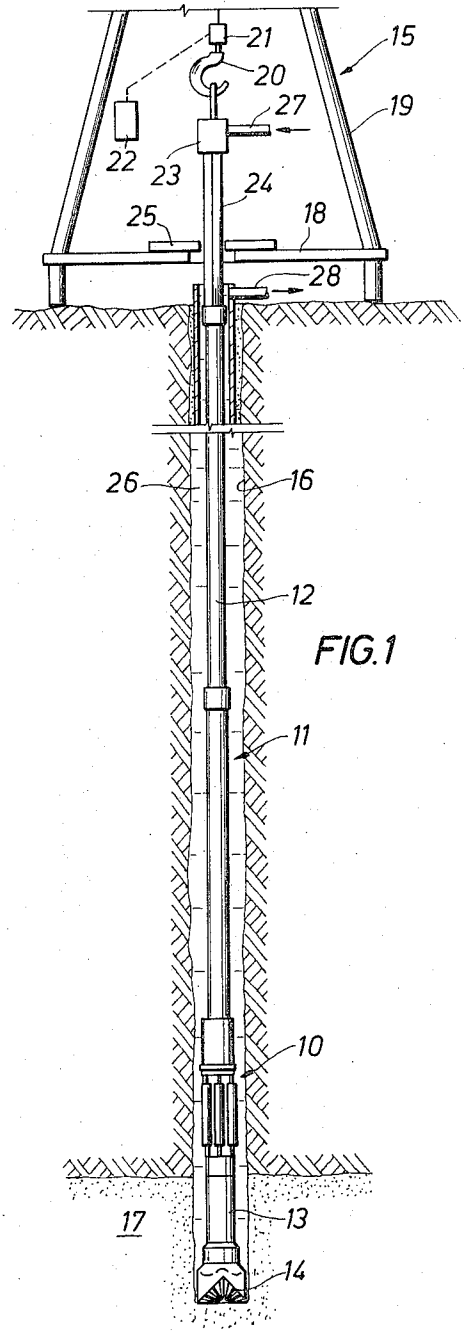


FIG. 1

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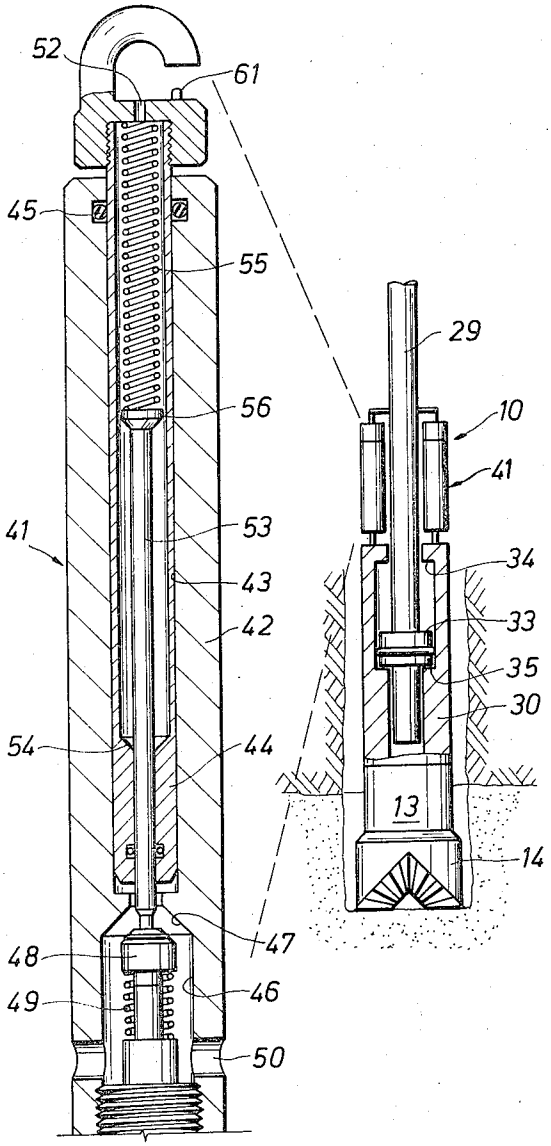


FIG. 3A

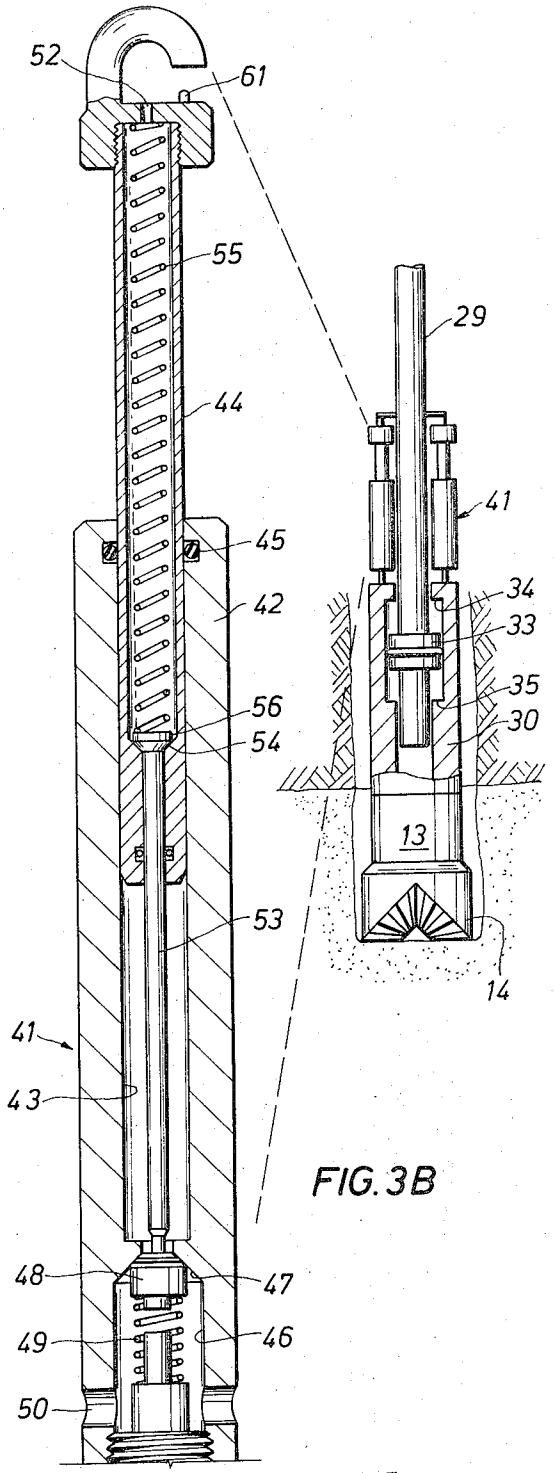


FIG. 3B

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FIG. 3C

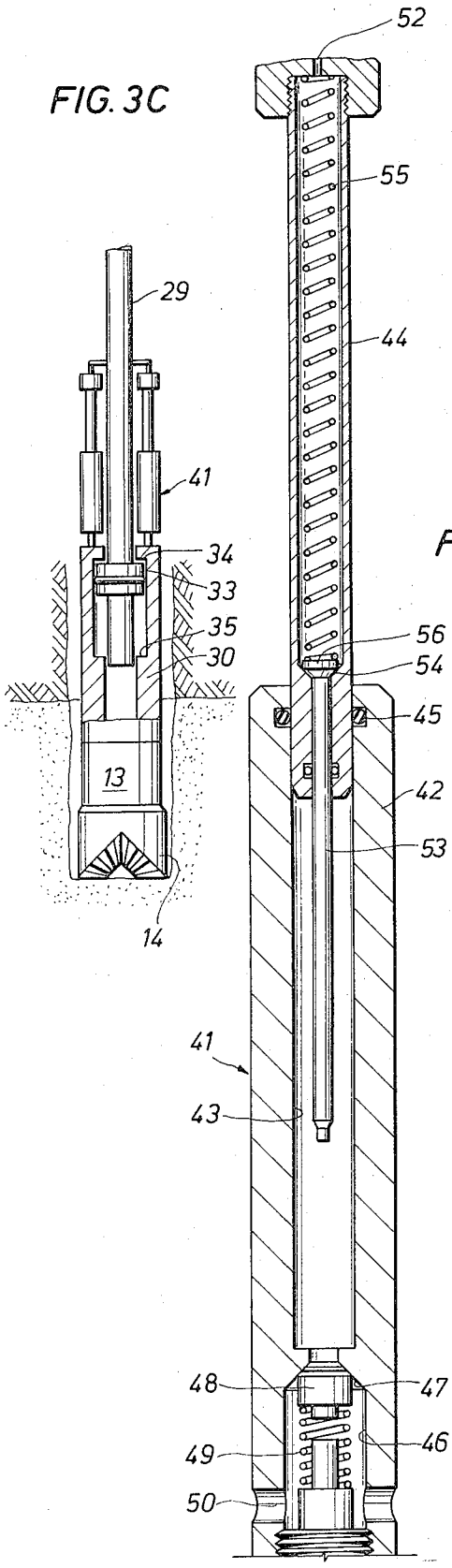


FIG.4A

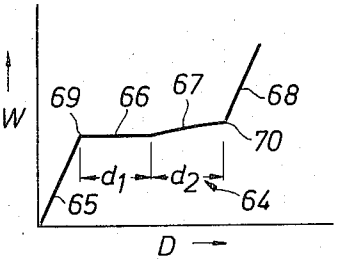


FIG.4B

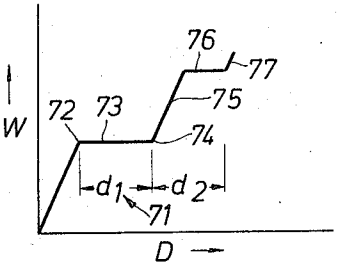


FIG.4C

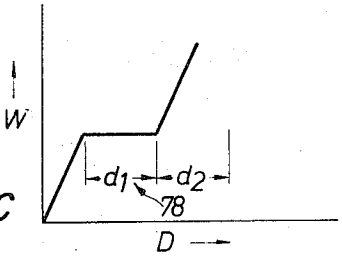
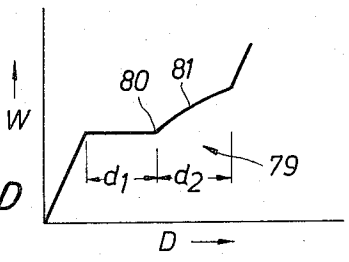


FIG.4D



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FIG. 5A

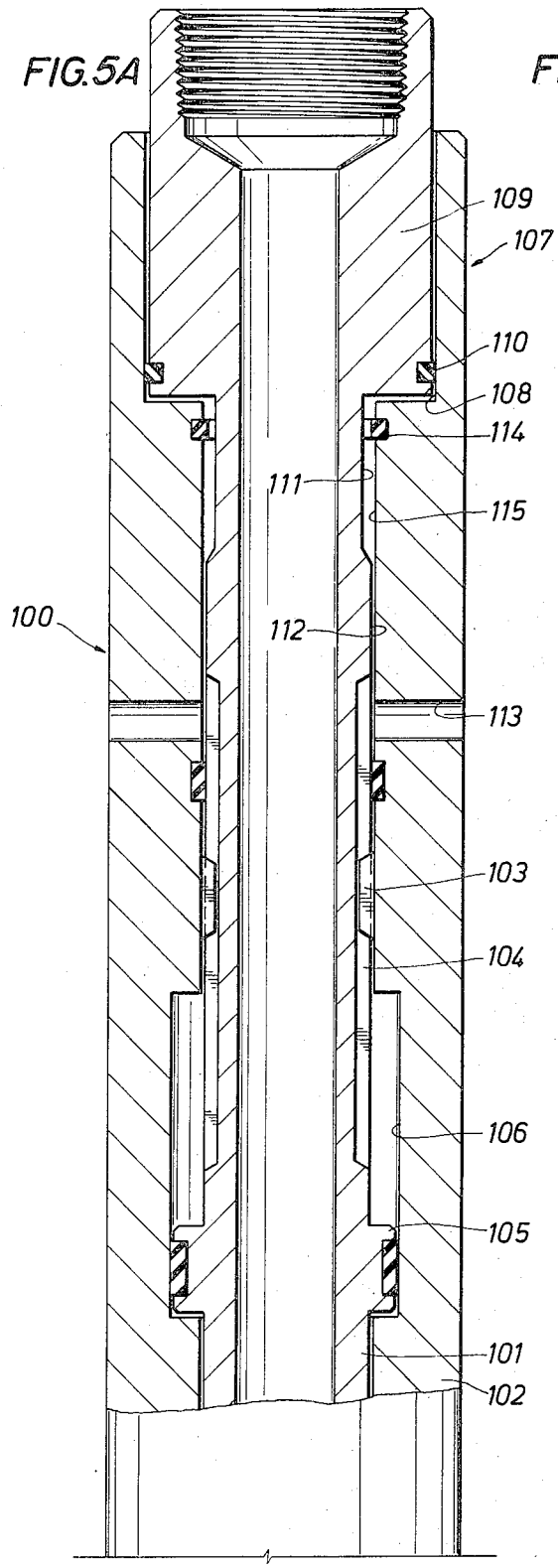
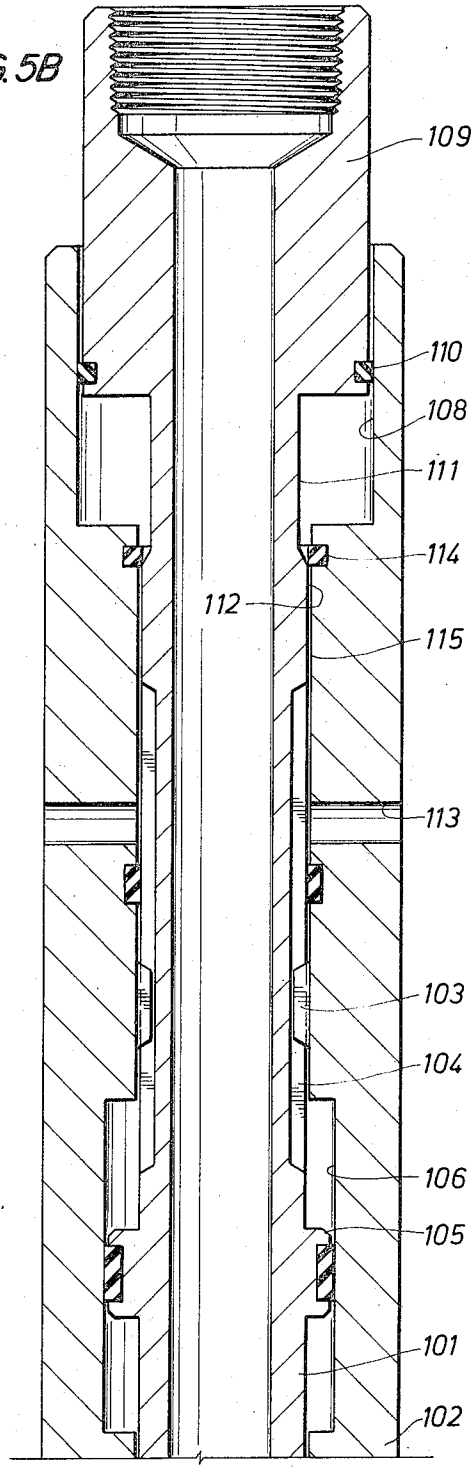


FIG. 5B



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FIG. 6A

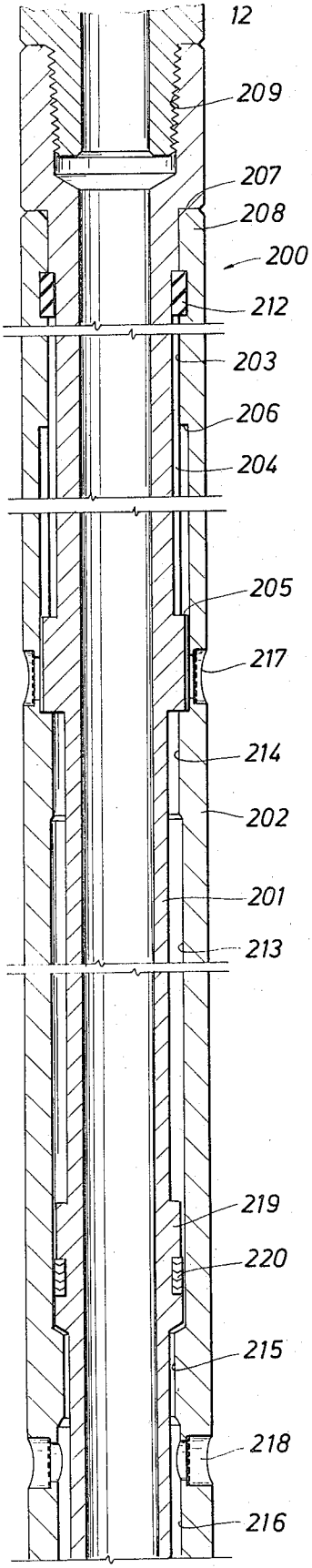
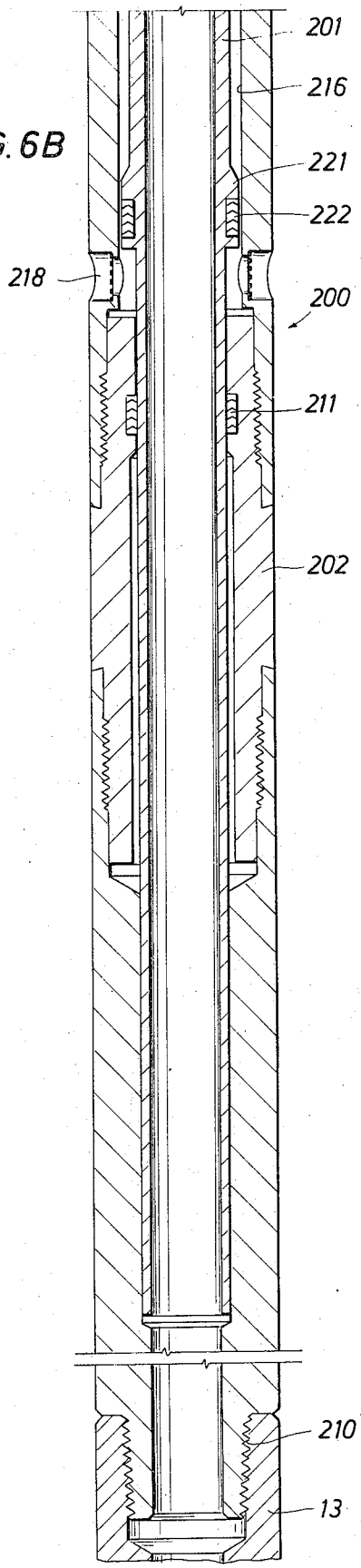

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FIG. 6B


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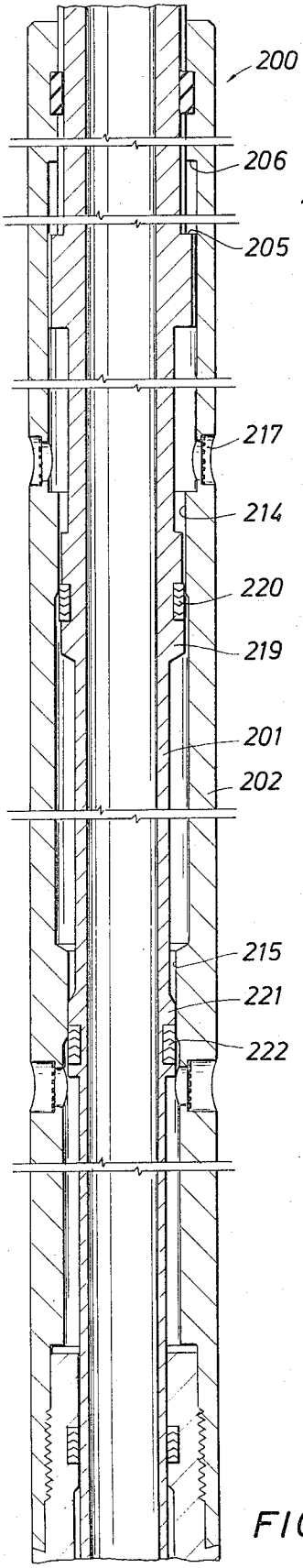


FIG. 7A

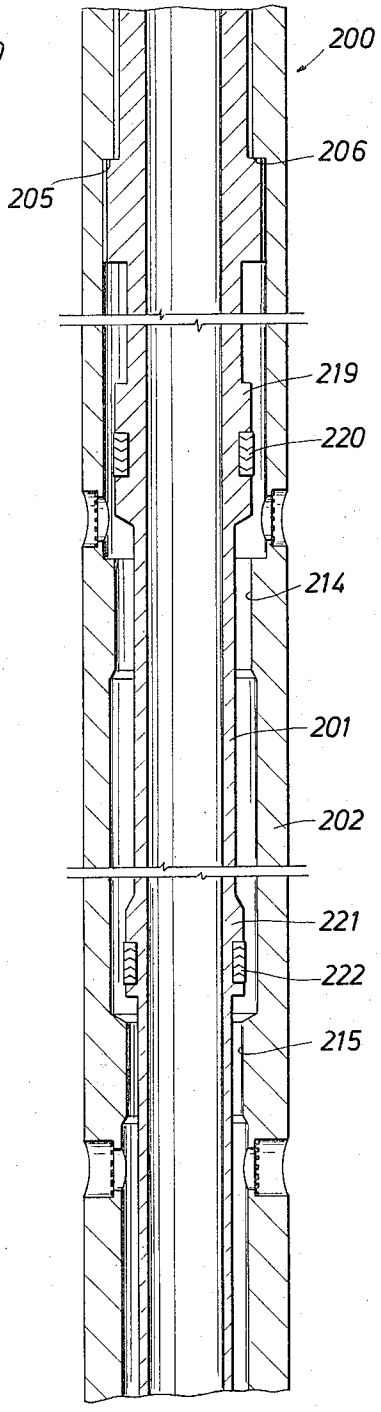


FIG. 7B

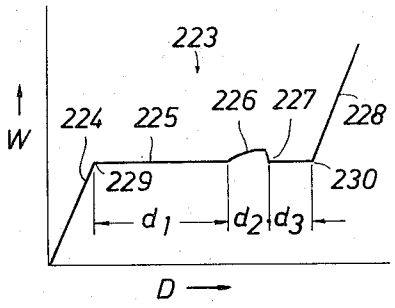


FIG. 8A

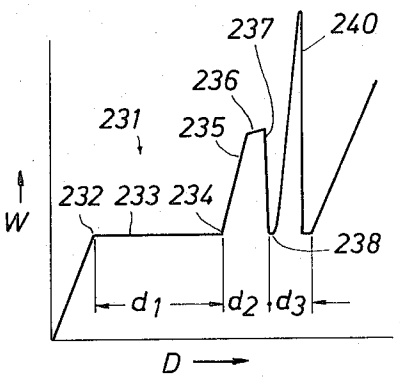


FIG. 8B

METHODS AND APPARATUS FOR DETECTING THE ENTRY OF FORMATION GAS INTO A WELL BORE

This application is a continuation is a continuation-in-part of application Ser. No. 105,885 filed Jan. 12, 1971, now abandoned.

Those skilled in the art will, of course, appreciate that while drilling an oil or gas well, a drilling fluid or so-called "mud" is customarily circulated through the drill string and drill bit and then returned to the surface by way of the annulus defined between the walls of the borehole and the exterior of the drill string. In addition to cooling the drill bit and transporting the formation cuttings removed thereby, the mud also functions to maintain pressure control of the various earth formations as they are penetrated by the drill bit. Thus, it is customary to selectively condition the drilling mud for maintaining its specific gravity or density at a sufficiently high level where the hydrostatic pressure of the column of mud in the borehole annulus will be sufficient to prevent or regulate the flow of high-pressure connate fluids which may be contained in the formations being penetrated by the drill bit.

It is, however, not at all uncommon for the drill bit to unexpectedly penetrate earth formations containing gases at pressures greatly exceeding the hydrostatic head of the column of drilling mud at that depth which will often result in a so-called "blowout". It will be appreciated that unless a blowout is checked, it may well destroy the well and endanger lives and property at the surface. Thus, to be abundantly safe, it might be considered prudent to always maintain the density of the drilling mud at excessively high levels just to prevent such blowouts from occurring. Those skilled in the art will appreciate, however, that excessive mud densities or so-called "mud weights" significantly impair drilling rates as well as quite often unnecessarily or irreparably damage potentially-producible earth formations which are uncased. As a matter of expediency, therefore, it is preferred that the drilling mud be conditioned so as to maintain its density at a level which is just sufficient to at least regulate, if not prevent, the unexpected entry of high-pressure formation fluids into the borehole and instead rely upon one or more of several typical operating techniques for hopefully detecting the presence of such formation fluids in the borehole.

Many techniques have, of course, been proposed for detecting the presence of such high-pressure fluids in the borehole with varying degrees of accuracy. For example, detection techniques which may be used include observing changes in the rotative torque as well as the longitudinal drag on the drill string, monitoring differencees between the flow rates of the inflowing and outflowing streams of the drilling mud as well as measuring various properties of the returning mud stream and the cuttings being transported to the surface thereby. Those skilled in the art will appreciate, however, that none of the several techniques which are presently employed will reliably and immediately detect the entry of high-pressure gases into the borehole. For example, variations of torque or drag on the drill string are not always reliable indications since borehole conditions entirely unrelated to the presence of high-pressure gases in the borehole mud can be wholly responsible for causing significant variations in these parameters. On the other hand, although such techniques as monitoring of the mud flow rates or measuring the physical characteristics of the returning mud stream may well reliably indicate the entrance of high-pressure formation gases into the borehole, the interval of time required for a discrete volume of mud containing such gases to reach the surface may well be in the order of several hours. This, of course, will usually be too late to permit preventative measures to be taken to avoid a disastrous blowout.

Accordingly, it is an object of the present invention to provide new and improved methods and apparatus for reliably detecting the entrance of even minor amounts of formation gas into a borehole being drilled and then immediately providing a positive indication at the surface that such gases are present.

This and other objects of the present invention are attained by entrapping a sample of drilling mud in a variable-volume fluid chamber which is cooperatively coupled to the drill string at a selected location above the drill bit and adapted for expansion upon predetermined movement of the drill string; moving the drill string to expand the fluid chamber for reducing the pressure of the drilling mud sample to at least the saturation pressure at the ambient borehole temperature of a gas-containing drilling mud; and measuring the force applied to the drill string for expanding the fluid chamber for determining a function which is characteristic of the presence or absence of gas in the drilling mud sample.

To practice the methods of the present invention, the preferred embodiments of the new and improved apparatus described and claimed herein each include a pair of telescoped members which are tandemly coupled in the drill string for selective movement between extended and contracted positions. Piston and chamber members are cooperatively arranged between the telescoping members for defining a variable-volume sample chamber having a minimum volume when the telescoping drill string members are in one of their positions and a maximum volume whenever the drill string members are moved to their other position. Valve means are cooperatively arranged for admitting only a predetermined volume of drilling mud into the sample chamber in response to a predetermined movement of the telescoping members so that, upon movement of the telescoping members toward their other position, the volume of the sample chamber will be sufficiently expanded to insure that the pressure of the entrapped mud sample will be reduced to at least the saturation pressure of a gas-containing mud sample at ambient borehole temperatures. Means are further provided for measuring the force applied to the drill string for accomplishing the expansion of the sampling chamber so that determinations may be readily made at the surface as to whether or not the drilling mud sample is free of entrained formation gas.

The novel features of the present invention are set forth with particularity in the appended claims. The invention, together with further objects and advantages thereof, may be best understood by way of the following description of exemplary methods and apparatus employing the principles of the invention as illustrated in the accompanying drawings, in which:

FIG. 1 schematically illustrates a portion of typical rotary drilling rig and its associated equipment and drill string along with one embodiment of apparatus arranged in accordance with the present invention;

FIG. 2 is an enlarged cross-sectional view of the embodiment of the present invention shown in FIG. 1;

FIGS. 3A–3C successively depict various positions of the apparatus illustrated in FIG. 2 during the performance of the methods of the present invention;

FIGS. 4A–4D graphically represent certain principles of the present invention;

FIG. 5A is a view similar to FIG. 2 but showing an alternative embodiment of apparatus arranged in accordance with the principles of the present invention;

FIG. 5B depicts the apparatus of FIG. 5A during the performance of the methods of the present invention;

FIGS. 6A and 6B are successive, enlarged cross-sectional views of another preferred embodiment of apparatus of the present invention;

FIGS. 7A and 7B schematically depict successive positions of the apparatus illustrated in FIGS. 6A and 6B during its operation; and

FIGS. 8A–8B graphically represent the operational principles of the apparatus of the present invention depicted in FIGS. 6A and 6B.

Turning now to FIG. 1, a new and improved testing tool **10** arranged in accordance with the present invention is depicted as being tandemly coupled in a typical drill string **11** comprised of a plurality of joints of drill pipe **12**, one or more drill collars **13**, and a rotary drilling bit **14**. As is customary, the drilling operation is accomplished by means of a typical drilling rig **15** which is suitably arranged for drilling a borehole **16** through various earth formations, as at **17**, until a desired depth is reached. To accomplish this, the drilling rig **15** conventionally includes a drilling platform **18** carrying a derrick **19** which supports conventional cable-hoisting machinery (not shown) suitably arranged for supporting a hook **20** which is coupled thereto by means of a weight-measuring device **21** having an indicator or recorder **22** arranged therewith. As is customary, the hoisting hook **20** supports a so-called "swivel" **23** and a tubular "kelly" **24** which is coupled in the drill string **11** to the uppermost joint of the drill pipe **12** and is rotatively driven by a rotary table **25** operatively arranged on the rig floor **18**. The borehole **16** is filled with a supply of drilling mud **26** for maintaining pressure control of the various earth formations, as at **17**; and the drilling mud is continuously circulated between the surface and the bottom of the borehole during the course of the drilling operation for cooling the drill bit **14** as well as for carrying away earth cuttings as they are removed by the drill bit. To circulate the drilling mud **26**, the drilling rig **15** is provided with a conventional mud-circulating system including one or more high-pressure circulating pumps (not shown) that are coupled to the kelly **24** and the drill pipe **12** by means of a flexible hose **27** connected to the swivel **23**. As is typical, the drilling mud **26** is returned to the surface through the annulus in the borehole **16** around the drill string **11** and discharged via a discharge conduit **28** into a so-called "mud pit" (not shown) from which the mud-circulating pumps take suction.

Turning now to FIG. 2, an enlarged cross-sectional view is depicted of the upper portion of the well tool **10**. As seen there, the new and improved testing tool **10** includes an elongated tubular mandrel **29** which is coaxially arranged in an elongated tubular body **30** and adapted for longitudinal movement in relation thereto between the contracted position illustrated and a fully-extended position. To define the longitudinal positions of the telescoping members relative to one another, an inwardly-opening recess **31** is provided within the axial bore **32** of the body **30** and adapted for receiving an enlarged-diameter shoulder **33** on the mandrel **29**. It will be appreciated, therefore, that the extent of the longitudinal travel of the telescoping members **29** and **30** is determined by the longitudinal spacings between the mandrel shoulder **33** and the opposed body shoulders which are respectively defined by the upper and lower surfaces **34** and **35** of the enlarged recess **31**. One or more inwardly-projecting splines **36** are cooperatively arranged on the body **30** and slidably received within complementary elongated grooves **37** formed longitudinally along the exterior of the mandrel **29** for corotatively securing the telescoping members to one another. In this manner, the telescoping members **29** and **30** are co-rotatively secured to one another for transmitting the rotation of the drill pipe **12** through the testing tool **10** to the drill collars **13** and the drill bit **14** therebelow.

To couple the tool **10** into the drill string **11**, a socket is formed in the upper end of the mandrel **29** and appropriately threaded, as at **38**, for threaded engagement with the lower end of the next adjacent joint of the drill pipe **12**. Although the lower portion of the tool **38** is not illustrated in FIG. **2**, it will be appreciated that the lower end of the body **30** is either similarly arranged or provided with male threads adapted for threaded engagement within a complementary threaded socket on the upper end of the next-adjacent drill collar as at **13**. In the preferred embodiment of the well tool **10**, a fluid seal **39** is provided on the enlarged mandrel shoulder **33** for sealing engagement with the inner wall of the recess **31** and one or more wipers **40** are arranged around the upper end of the body **30** to remove accumualtions of mud and the like from the spline grooves **37** and the exterior of the mandrel **29**.

Of particular significance to the present invention, the new and improved testing tool **10** further includes one or more similar or identical fluid-sampling devices, as at **41**, which are cooperatively arranged between the telescoping members **29** and **30** for selective operation upon longitudinal movements of the members in relation to one another. In the preferred embodiment of the testing tool **10** shown in FIG. **2**, each of the sampling devices **41** includes an elongated body **42** having a longitudinal bore formed in its upper portion and defining a chamber **43** in which an elongated piston **44** is telescopically arranged and adapted for sliding movement relative to the body between the contracted position illustrated and one or more extended positions to be subsequently described. Sealing means, such as a suitable O-ring **45** cooperatively arranged near the upper end of the piston chamber **43**, are provided for fluidly sealing the piston **44** in relation to the body **42**. The lower portion of the body **42** is cooperatively arranged to provide an enlarged chamber **46** which is separated from the piston chamber **43** by an inwardly-directed annular shoulder having its lower face suitably shaped, as at **47**, for defining an annular valve seat adapted for complementally receiving a valve member **48** which is movably disposed in the enlarged chamber. Biasing means, such as a relatively-weak compression spring **49**, are cooperatively arranged in the chamber **46** between the body **42** and the valve member **48** for

normally maintaining the valve member in seating engagement with the valve seat 47. One or more lateral ports, as at 50, are arranged in the body 42 to provide fluid communication between the borehole 16 and the enlarged chamber 46.

For reasons that will subsequently become apparent, the piston member 44 is cooperatively arranged to provide an axial bore 51 therein which has a venting passage 52 at its upper end and receives an elongated rod 53 that is slidably disposed therein and extended downwardly therefrom through a reduced-diameter annular shoulder 54 at the lower end of the bore. Biasing means, such as a moderately-strong spring 55 positioned in the axial bore 51 between the upper end of the piston member 44 and an enlarged head 56 on the rod 53, are cooperatively arranged for normally urging the rod downwardly through the valve seat 47 and into engagement with the opposed face of the valve member 48. Thus, as depicted in FIG. 2, so long as the piston 44 remains in its fully-contracted position in relation to the body 42, the stronger biasing spring 55 will extend the rod 53 through the valve seat 47 and urge the rod tip against the valve member 48 for maintaining it out of seating engagement with the valve seat.

In the preferred manner of coupling one or more of the sampling devices 41 are to the tool 10, the upper and lower ends of the piston 44 and the elongated body 42 are respectively secured to the telescoping members 29 and 30 by means such as hooks 57 and 58 which are releasably coupled to transversely-positioned pins 59 and 60 on the telescoping members respectively. Spring-loaded detents, as at 61, are arranged for retaining the hooks 57 and 58 on their respective pins 59 and 60. To minimize the overall exterior diameter of the tool 10, it is preferred to form appropriately-shaped longitudinal recesses, as at 62 and 63, in the telescoping members 29 and 30 so that once the sampling devices 41 releasably secured thereto, they will be substantially or entirely confined within the exterior circumference of the tool to reduce the likelihood that the sampling devices might be damaged as the tool is being operated in the borehole 16.

Turning now to FIGS. 3A–3C, successive schematic views are shown of the well tool 10 during the course of a testing operation, with greatly-enlarged views being shown in each FIG. of one of the fluid sampling devices 41 as these elements will appear while a test is being made in accordance with the methods of the invention to determine whether or not gas is then present in the drilling mud 26. As depicted in FIG. 3A, the telescoping members 29 and 30 of the new and improved tool 10 are initially fully contracted in relation to one another and the body 42 and the piston 44 of the fluid-sampling device 41 will likewise be in their fully-contracted positions in relation to one another. So long as the piston member 44 is fully retracted within the body 42, the spring 55 will be effective for urging the rod 53 downwardly against the valve member 48. Since the spring 55 is somewhat stronger than the spring 49, the net effect will be for the rod 53 to maintain the valve member 48 spatially disposed below and out of contact with the valve seat 47. Thus, the drilling mud 26 in the borehole 16 immediately exterior of the fluid-sampling device 41 will be free to enter the chamber 46 by way of the ports 50 to fill the lowermost portion of the elongated bore 43 below the piston 44. It will be recognized, of course, that by virtue of the venting passage 52, there are no unequal pressure forces acting on the sampling device 41 and the piston 44 will remain fully retracted. The spring 55 will be effective for urging the rod 53 downwardly to maintain the valve member 48 open against the counteracting closing force of the spring 49.

It will be appreciated that if the drill string 11 is elevated, the mandrel 29 will be free to travel upwardly relative to the longitudinally-stationary body 30 until the shoulder 33 engages the shoulder 34. Conversely, if the drill string 11 is maintained at the same vertical or longitudinal position in relation to the borehole 16 while the drill string is being rotated, as the drill bit 14 progressively cuts away the formation materials in contact therewith the weight of the drill collars 13 will carry the body 30 downwardly in relation to the longitudinally-stationary mandrel 29 until such time that the shoulder 33 contacts the shoulder 34. Thus, in either event, the net effect will be to progressively move the telescoped members 29 and 30 as well as the body 42 and the piston 44 from their respective retracted positions illustrated in FIG. 3A toward their respective more-extended positions illustrated in FIG. 3B.

It will be appreciated, therefore, that upon expansion of the free space within the axial bore 43 as the piston member 44 moves upwardly in relation to the elongated body 42, the piston member will induct a discrete volume of the mud 26 into the sampling device 41. As will be noted by comparison of FIGS. 3A and 3B, it will be recognized that the valve member 48 will remain disengaged from the valve seat 47 until such time that the inwardly-directed shoulder 54 in the elongated piston 44 comes into contact with the enlarged head 56 on the upper end of the rod 53. Thus, as shown in FIG. 3B, once the shoulder 54 engages the enlarged head 56, the spring 55 is no longer effective for urging the rod 53 downwardly so that further upward movement of the piston 44 in relation to the body 42 will disengage the tip of the rod from the valve member 48 so that the spring 49 will then urge the valve member into seating engagement with the valve seat 47. Once this occurs, therefore, it will be recognized that a discrete volume of the drilling mud 26 will then be entrapped within the free portion of the axial bore 43 as defined at that time between the lower end of the piston 44 and the valve seat 47. Accordingly, it will be recognized that any further upward movement of the piston member 44 in relation to the body 42 must result in a reduction of the pressure of the entrapped sample of the drilling mud 26 before the tool 10 can assume the position illustrated in FIG. 3C.

To understand the principles of the methods and apparatus of the present invention, it must be recognized that the physical characteristics of the mud sample entrapped in the piston chamber 43 will determine the sequence of events upon further upward movement of the mandrel 29 and the piston member 44. First of all, those skilled in the art will appreciate that if only a gas were entrapped in the piston chamber 43, further upward travel of the piston member 44 from its intermediate position shown in FIG. 3B toward its fully-extended position depicted in FIG. 3C would simply cause the gas to expand accordingly. Thus, in this unlikely situation, there would be no significant forces restraining upward travel of the mandrel 29 and the piston 44 which is coupled thereto. The pressure of the en-

trapped gas sample would merely be reduced in keeping with the general gas laws.

As a result, an observer at the surface viewing the weight indicator 22 will note a steady increase in the measured reading as upward movement of the drill string 11 progressively picks up the weight of the drill pipe 12 and the mandrel 29. Once the shoulder 33 is disengaged from the shoulder 35, the weight indicator 22 will show the entire weight of the kelly 24, the drill pipe 12, and the mandrel 29. This reading will, of course, remain unchanged until the shoulder 33 engages the shoulder 34. From that point on, continued upward movement of the drill string 11 will produce a continued increase in the reading shown on the indicator 22 until the drill bit 14 is picked up from the bottom of the borehole 16. The total reading shown on the weight indicator 22 will, of course, then be the full weight on the entire drill string 11.

As shown in FIG. 4A, the readings, W, of the weight indicator 22 in this particular situation when plotted against the upward travel, D, of the drill string 11 will be generally as graphically represented by the curve 64. These readings will, therefore, first follow an ascending sloping line, as at 65, until the shoulder 33 is first disengaged from the shoulder 35. The indicated weight, W, will then, as indicated at 66, remain constant over that portion of the tool stroke, d_1, where the shoulder 33 is moving away from the shoulder 35 and until the valve member 48 is seated on the valve seat 47 (FIG. 3B). As previously mentioned, even when a gas is trapped in the piston chamber 43 by closure of the valve member 48, the remaining travel, d_2, of the piston 44 will be without significant restraint so that the reading on the weight indicator 22 will remain substantially unchanged (as graphically represented at 67 in FIG. 4A) until the shoulder 33 engages the shoulder 34.

Thereafter, as graphically represented at 68, further upward travel, D, of the drill pipe 12 will again produce an increasing reading, W, on the weight indicator 22 as the weight of the drill collars 13 is progressively added to that of the drill pipe already supported by the hook 20.

Accordingly, it will be recognized that if only a purely-gaseous sample is trapped in the piston chamber 43, the readings on the weight indicator 22 will generally be as represented by the curve 64 in FIG. 4A. The abrupt changes, as at 69 and 70, in the slope of the curve 64 will clearly define the points during the new and improved testing operation when the shoulder 33 is respectively disengaging from the shoulder 35 and engaging the shoulder 34. Those skilled in the art will appreciate, therefore, that readings such as those just described will be readily apparent at the surface since the respective weights of the drill pipe 12 on the one hand and those of the drill collars 13 and the drill bit 14 on the other hand are always known with a fair degree of accuracy.

The situation just described will, of course, be significantly different where closure of the valve member 48 traps a sample in the piston chamber 43 that is entirely a liquid. If this is the case, continued upward travel of the drill pipe 12 will simply be incapable of producing further extension of the piston 44 in relation to the body 42 until or unless the forces tending to pull the piston and the body apart are sufficient to reduce the pressure of the entrapped liquid sample to its saturation pressure at the existing ambient borehole temperature. This will, of course, induce flashing of the entrapped liquid sample. In this event, once flashing of the liquid sample commences, the piston 44 will then be free to move upwardly toward its extended position until the shoulder 33 engages the shoulder 34.

As shown in FIG. 4B, therefore, the readings, W, on the indicator 22 will generally vary as represented by the graph 71 where the entrapped sample is initially completely liquid but is ultimately reduced to its saturation pressure at the ambient borehole temperature. Initial upward movement of the piston 44 toward its intermediate position (FIG. 3B) will again cause a steady increase in the reading, W, on the weight indicator 22 until the shouder 33 disengages from the shoulder 35 (the point 72 on the curve 71). Then, there will be no further increase in weight (as shown by the line segment 73) until the valve 48 is seated on its associated seat 47 (the point 74 on the curve 71). Further upward travel, D, of the drill pipe 12 will then produce a second steady increase of observed weight as shown at 75 on the curve 71.

Once the forces tending to separate the piston 44 and the body 42 are sufficient to reduce the pressure of the entrapped liquid sample to its saturation pressure at the ambient temperature and flashing of the sample is commenced, as shown at 76 in FIG. 4B there will be no significant increase in the reading on the weight indicator 22 until the shoulders 33 and 34 are engaged to begin imposing the combined weight of the drill collars 13 and the bit 14 onto the hook 20. This will then cause an increasing reading, W, on the indicator as shown at 77.

The third situation that may occur is where a wholly-liquid sample is trapped in the piston chamber 43 but the forces tending to separate the piston 44 and the body 42 are insufficient to induce flashing of the trapped liquid sample. It will be appreciated that this can occur where, for a given size of the piston, there is an insufficient number of drill collars 13 in the drill string 11 below the tool 10 to impose a sufficient downward force on the tool for allowing the piston 44 to be fully extended. Thus, the combined weight of the drill collars 13 and the drill bit 14 is a limiting factor for determining whether a completely-liquid sample will be flashed during the practice of the present invention. As shown in FIG. 4C, therefore, this situation is graphically represented at 78. It will be recognized that the curve 78 is similar to the left-hand portion of the curve 71 in FIG. 4B so further explanation is believed unnecessary. It should be noted, of course, that the shoulder 33 will not engage the shoulder 34 so that extension of the tool 10 will be halted just after the valve member 48 has closed.

The situation graphically illustrated in FIG. 4D is where a liquid mud sample has only a small percentage of entrained gas. This is, of course, what should usually be expected where a high-pressure gas is initially entering the borehole 16 and a blowout is possibly commencing. As shown in FIG. 4D by the curve 79, the initial operation of the tool 10 while performing the methods of the present invention will be similar to the previously-described situations. Once, however, the valve 48 is seated, as at 80 on the curve 79, the continued upward travel of the drill pipe 12 will induce movement of the piston 44 toward its fully-extended position with substantially less force being required than where the entrapped sample is wholly liquid. This will be readily

understood when it is realized that the presence of entrained gas in an entrapped liquid sample will make the saturation pressure of the mixture correspondingly higher than that of a purely lquid sample. Thus, less force is required to fully extend the telescoping members 29 and 30 and the body 42 and the piston 44. This is graphically represented by the curved segment 81 of the curve 79.

Accordingly, it will be recognized by considering FIGS. 4A–4D that the relationship of the force applied for elevating the drill pipe 12 to fully extend the telescoping members 29 and 30 will be wholly dependent upon the physical state of the sample which is entrapped in the piston chamber 43 upon closure of the valve member 48. Thus, as shown in FIG. 4A, if the entrapped sample is purely gas, there will be no significant increase in the force required to move the telescoping members 29 and 30 from their fully-contracted position to their fully-extended position. On the other hand, FIGS. 4B and 4C demonstrate that if the entrapped sample is solely a liquid, once the valve member 48 has been seated there will be a significant and readily-recognizable increase in the force required to move the telescoping members 29 and 30 to their fully-extended position — if such is ever reached. As graphically represented in FIG. 4D, however, the presence of even a small percentage of gas which may be entrapped in an otherwise wholly-liquid sample will produce only a slowly-ascending increase of the weight reading, W, on the indicator 22. Accordingly, it will be recognized that in any of the four above-described situations, observing the readings, W, of the weight indicator 22 in conjunction with the upward travel, D, of the exposed end of the drill pipe 12 will provide a readily-detectable surface indication of the state of the drilling mud 26 which is then adjacent to the testing tool 10 of the present invention.

The preceding descriptions have assumed that the testing operations were conducted by elevating the drill pipe 12 in relation to the drilling platform 18. It will be appreciated, however, that identical reactions will be obtained where the drill pipe 12 is maintained at about the same longitudinal position as the drill string 11 is being rotated. If this is the situation, it will be recognized that as the drill bit 14 continues to cut away at the bottom of the borehole 16, the weight of the drill collars 13 and the drill bit will tend to carry the bodies 30 and 42 downwardly in relation to the longitudinally-stationary mandrel 29 and the piston member 44. Thus, the same results as previously described will be obtained.

In other words, downward movement of the drill bit 14 will progressively carry the body 42 downwardly in relation to the longitudinally-stationary piston member 44 so that the valve member 48 will ultimately be closed once the enlarged rod head 56 engages the shoulder 54. Thereafter, the weight reading, W, which will be registered by the indicator 22 will again be determined by the nature or state of the entrapped fluid within the piston chamber 43. Stated another way, since the combined weight of the drill collars 13 and the drill bit 14 represent the maximum force which can be effective for moving the testing tool 10 to its fully-extended position, the above detailed descriptions are equally applicable regardless of whether it is the upper member 29 and 44 which are being moved upwardly in relation to the longitudinally-stationary lower members 30 and 42 or it is the lower members which are being moved downwardly in relation to the longitudinally-stationary upper members. In either case, easily-recognized surface indications will be provided to warn the observer of an impending blowout.

Turning now to FIG. 5A, an enlarged cross-sectional view is shown of the upper portion of another testing tool 100 which is arranged in accordance with the principles of the present invention. The testing tool 100 includes an elongated tubular member 101 which is coaxially disposed within an elongated tubular body 102 and suitably arranged for longitudinal movement in relation thereto between the depicted retracted position and a fully-extended position. It will, of course, be recognized by comparison of FIGS. 2 and 5A that the testing tool 100 is somewhat similar to the testing tool 10. Thus, for similar reasons, the telescoping members 101 and 102 are co-rotatively secured to one another as by one or more sets of mating splines and grooves as at 103 and 104. Similarly, an enlarged-diameter shoulder 105 on the mandrel 101 is cooperatively arranged within a recess 106 provided within the tool body 102 for establishing the contracted and extended positions of the telescoping members. Other similar details will be noted.

The significant difference between the tool 10 and the tool 100 is, however, that the latter tool has an integral fluid-sampling device shown generally at 107 which is cooperatively arranged between the telescoping members 101 and 102 for operation in a similar fashion to the first-described testing tool. In the preferred embodiment of the testing tool 100 shown in FIG. 5A, the sampling device 107 is provided by arranging a piston chamber 108 in the upper end of the body 102 which receives an enlarged-diameter portion 109 of the mandrel 101 having a fluid seal 110 operatively disposed therearound. In this manner, upon upward movement of the mandrel 101 in relation to the body 102, the free space in the piston chamber 108 will be expanded in a similar manner as the sampling devices 41.

To accomplish the necessary valving action such as previously described in relation to the sampling devices 41, that portion of the mandrel 101 immediately below the enlarged-diameter piston member 109 is reduced in diameter, as at 111, and the next immediately-adjacent portion of the mandrel is enlarged in diameter, as at 112, to provide a valve member. In this manner, on the initial upward movement of the mandrel 101, the expansion of the piston chamber 108 will induce a flow of the drilling mud 26 through one or more lateral ports 113 arranged in the body 102 below an inwardly-facing seal 114 which is mounted in the interior bore 115 of the body to provide a valve seat for the enlargement 112. Thus, drilling mud will be drawn into the progressively enlarged piston chamber 108 until the enlarged-diameter portion 112 of the mandrel 101 first engages the sealing member 114. At this point, a discrete sample of the drilling mud 26 will be entrapped within the piston chamber 108 so that further upward travel of the mandrel 101 in relation to the body 102 will produce the same variations on the weight indicator 22 as those previously described with reference to FIGS. 4A–4D.

From the foregoing descriptions of the new and improved testing tools 10 and 100, it will be appreciated from FIGS. 4A–4D that an observer at the surface can

readily deduce from the changes in the weight readings, W, on the indicator 22 in association with upward movement of the drill string 11 whether or not gas is then present in the borehole 16 in the vicinity of the drill collars 13. Thus, a simple "go-no go" type of test can be readily performed during the course of the drilling operation merely by elevating the drill string 11 a sufficient distance to fully extend the telescoping members of the testing tool 10 (or 100) and observing the resulting effects as visibly displayed on the weight indicator 22. A test of this nature can, of course, be rapidly conducted with no appreciable interruption of the drilling operation. Moreover, if necessary, several tests can be conducted for verification by simply lowering the drill string 11 to expel the first sample and reposition the various elements of the testing tool 10 (or 100).

It should be noted that the new and improved testing tools 10 and 100 are also capable of performing the methods of the present invention without raising the drill string 11. Thus, at any time during a drilling operation, if the drill string 11 is slacked off to be certain that the telescoping members of the testing tool 10 (or 100) are in their respective fully-telescoped positions, as the drilling operation commences the drill bit 14 will progressively deepen the borehole 16 to move the telescoping members toward their extended positions. An observer can, therefore, note the time interval required for the telescoped members of the testing tool 10 (or 100) to move to the point where the valve member 48 is first seated (or the enlarged portion 112 is first sealingly engaged with the seal 114). This time interval can, of course, be readily determined at the surface since the pronounced cessation of the increasing weight indications which occurs once the full weight of the drill pipe 12 is suspended on the hook 20 will identify when the telescoping members first start moving and the next change in the weight indication will show when the valve member is first seated.

Once it is known how long it takes for the valve member of the testing tool 10 (or 100) to be closed, it can be safely assumed that the same time interval will be required for the telescoping members to move to their fully-extended positions since the valve closes at the mid-point of the stroke of the tool. A proportional relationship will, of course, always exist between the times required and d_1 and d_2 irrespective of the actual point in the stroke of the telescoping members that the valve member is seated. Accordingly, by observing the variations in the indicated weight, W, during this second time interval, an observer can reliably deduce whether gas is then present in the borehole 16 adjacent to the drill collars 13. Hereagain, if during drilling an indication is routinely obtained that gas is or may be present, it is quite easy to lower the drill pipe 12 to expel the mud sample then in the testing tool 10 (or 100) and then either continue drilling or else elevate the drill pipe to make a second test for verifying the first test.

It has been found, however, that the new and improved methods and apparatus of the present invention can also be employed for quantitatively measuring with a fair amount of precision the amount of gas entering the borehole 16 during the course of the drilling operation. As previously described, the various dimensions of the testing tools 10 and 100 are, of course, known. Thus, by measuring the additional force, ΔW, required to extend the piston 44 (or 109) from just after the point that the fluid sample has been entrapped to the point where the piston is fullyextended, a unique relationship between this force and the tool displacement d_2, is determined by the percentages of gas — if any — which is then entrained in the entrapped sample. As previously described with reference to FIGS. 4B and 4C, if the entrapped sample is wholly liquid, the rapid changes in the indicated weight, W, on the indicator 22 through the stroke, d_2, of the piston member 44 (or 109) within the piston chamber 43 (or 108) will provide a positive indication at the surface that the entrapped sample is wholly free of any entrained gas. Conversely, the force required for moving the piston member 44 (or 109) to its fully-extended position will be directly related to the percentage of gas which is then entrained in the entrapped fluid sample. This unique relationship is expressed by the equation:

$$\% \text{ gas (by volume)} = (d_1/d_2)\{[(P_h \times A)(W_2 - W_1)] - 1\} \times 100\% \quad \text{(Eq. 1)}$$

where,

d_1 = longitudinal displacement of the telescoping members required to induct a sample of mud into the piston chamber;

d_2 = maximum longitudinal displacement of the telescoping members between the point where the valve is closed to the point where the telescoping members are fully extended;

P_h = hydrostatic pressure of the drilling mud at the depth at which the sample is being taken;

A = cross-sectional area of the piston(s);

W_1 = weight indication at the time a sample is being inducted into the piston chamber; and

W_2 = weight indication when the telescoping members are first fully extended.

It should also be understood that once the sample is trapped in the piston chamber 43 (or 108), the force being indicated on the weight indicator 22 at any given point during the continued movement of the telescoping members 29 and 30 (or 101 and 102) will be directly related to the amount of entrained gas in the sample. This relationship is best expressed by the following equation:

$$\% \text{ gas (by volume)} = (\Delta d/d_2)[(W_{max} - W)/W] \times 100\% \quad \text{(Eq. 2)}$$

where,

Δd = longitudinal displacement of the telescoping members between the point where the valve is closed to the point where the measurement is being made;

d_2 = maximum longitudinal displacement of the telescoping members between the point where the valve is closed to the point where the telescoping members are fully extended;

W = weight indication at the time the measurement is being taken less the weight of the drill pipe or drill string above the tool. This latter weight must be corrected to account for the buoyancy of the drill pipe or drill string in the particular drilling mud being used; and

W_{max} = the product of depth, mud density, and the area of the sampling piston(s).

Turning now to FIGS. 6A–6B, successive enlarged cross-sectional views are depicted of another well tool 200 which also incorporates the principles of the present invention. As seen there, the new and improved testing tool 200 includes an elongated tubular mandrel

210 which is coaxially arranged in an elongated tubular body 202 and adapted for longitudinal movement in relation thereto between the contracted position illustrated in FIGS. 6A and 6B, a first intermediate position as schematically shown in FIG. 7A, a second intermediate position just above the first, and a fully-extended position as depicted in FIG. 7B. The body 202 is reduced slightly, as at 203, and provided with one or more elongated longitudinal grooves cooperatively arranged to slidably receive a corresponding number of outwardly-projecting splines 204 on the mandrel 201 for co-rotatively securing the telescoping members to one another (FIG. 6A). In this manner, when the tool 200 is substituted for the tool 10 shown in FIG. 1, the telescoping members 201 and 202 are co-rotatively secured to one another for transmitting the rotation of the drill pipe 12 through the testing tool 200 to the drill collars 13 and the drill bit 14 therebelow. Opposed shoulders 205 and 206 at the lower ends of the splines 204 and the reduced body portion 203 define the upper limit of telescopic movement of the telescoping 201 and 202 relative to one another. It will also be appreciated that the opposed shoulders 207 and 208 provided by the upper ends of the mandrel 201 and the body 202, respectively, will cooperate to define the lower travel limit or fully-contracted position of these two telescoping members.

To couple the tool 200 into the drill string 11, a socket is formed in the upper end of the mandrel 201 and appropriately threaded, as at 209, for threaded engagement with the lower end of the next adjacent joint of drill pipe 12. The lower end of the body 202 is either similarly arranged or provided with male threads, as at 210, adapted for threaded engagement within a complementary threaded socket on the upper end of the next-adjacent drill collar as at 13. In the preferred embodiment of the well tool 200, a fluid seal 211 is mounted within the lower end of the body 202 for sealing engagement with the lowermost portion of the mandrel 201; and one or more wipers 212 are arranged around the upper end of the body to remove accumulations of mud and the like from the splines 204 and the exterior of the mandrel.

The new and improved testing tool 200 is further arranged to define an expansible fluid-sampling chamber 213 between the inner and outer members 201 and 202, with the upper and lower limits of the chamber being determined by spaced, internally-reduced portions 214 and 215 in the axial bore 216 of the body. Fluid ports 217 and 218 are arranged in the body 202 above and below the seats 214 and 215 respectively to provide fluid communication between the axial bore 216 and the borehole 16 exterior of the tool 200.

The mandrel 201 is cooperatively arranged to include piston means, such as an enlarged piston member 219 having sealing members such as one or more chevron shaped seals 220 mounted thereon, adapted for inducting drilling mud from the borehole 16 into the sampling chamber 213 as the mandrel is moved upwardly in relation to the body 202 between its retracted position shown in FIGS. 6A and 6B and the first intermediate position schematically depicted in FIG. 7A. The mandrel 201 is also arranged to include valve means such as an enlarged valve member 221 spaced below the piston member 219 and carrying sealing members such as one or more downwardly-directed chevron shaped seals 222. As will subsequently be explained in greater detail, the seals 220 and 222 and the reduced bore portions 214 and 215 are cooperatively spaced so that once the mandrel 201 is in the intermediate position shown in FIG. 7A, the upper and lower seals will be sealingly engaged with the upper and lower reduced portions, respectively, to fluidly seal an entrapped mud sample in the chamber 213.

It will be appreciated from FIG. 7A, that during that part of the travel of the mandrel 201 in relation to the body 202 from the first intermediate position where the upper seals 220 first sealingly engage the upper reduced bore portion to the second intermediate position where the upper seals are no longer sealingly engaged with this bore portion, the volume of the sample chamber 213 will be increased in proportion to the difference in diameter of the upper and lower bore portions 214 and 215. Stated another way, as the mandrel 201 moves upwardly between the aforementioned intermediate positions, the volume of the sample chamber 213 will progressively expand as more of the larger-diameter piston member 219 moves out of the sample chamber and is replaced by the smaller-diameter valve member 221 on the mandrel.

The expansion volume of the sample chamber 213 will, of course, be determined by the difference in diameters between the two mandrel portions 219 and 221 (or, stated another way, the difference between the internal diameters of the reduced bore portions 214 and 215). The total or maximum-available expansion of the chamber 213 will, therefore, be limited to that which will be obtained as the mandrel 201 moves over the short distance where the seals 220 and 222 are both respectively engaged with the upper and lower bore portions 214 and 215. Thus, the sample chamber 213 will be expanded only as the mandrel 201 is moved between the two intermediate positions which occur only so long as both the upper and lower seals 220 and 222 are simultaneously sealingly engaged with their respective sealing surfaces 214 and 215. As seen in FIGS. 6A and 6B, the longitudinal spacing between these two intermediate positions of the inner and outer members 201 and 202 will, in general, be determined by the axial heights of the seals 220 and 222 as well as of the reduced-bore portions 214 and 215.

Once the mandrel 201 is moved further upwardly, however, the chamber 213 will be re-opened whenever one of the two seals 220 or 222 is no longer sealingly engaged with its associated sealing surface 214 or 215. Thus, it will be appreciated that in the operation of the new and improved tool 200, the piston 219 will ultimately be moved upwardly above the sample chamber 213 to release the sample from the chamber as the mandrel 201 is moved toward the fully-extended position of the tool 200 as defined by the abutment of the shoulders 205 and 206 and depicted in FIG. 7B.

It will be appreciated that if the drill string 11 is elevated, the mandrel 201 will be free to travel upwardly relative to the longitudinally-stationary body 202 until the shoulder 205 engages the shoulder 206. Conversely, if the drill string 11 is maintained at the same vertical or longitudinal position in relation to the borehole 16 while the drill string is being rotated, as the drill bit 14 progressively cuts away the formation materials in contact therewith the weight of the drill collars 13 will carry the body 202 downwardly in relation to the longitudinally-stationary mandrel 201 until such time that the shoulder 206 contacts the shoulder 205. Thus,

in either event, the net effect will be to progressively move the telescoped members 201 and 202 as well as the piston 219 and the valve member 221 from their respective positions illustrated in FIGS. 6A and 6B toward their respective positions illustrated in FIGS. 7A and 7B.

To determine whether or not gas is present in the drilling mud, the telescoping members 201 and 202 of the new and improved tool 200 are initially fully contracted in relation to one another so that the piston member 219 and the valve member 221 will be in their respective positions as depicted in FIGS. 6A and 6B. So long as the piston member 219 and the valve member 221 are in these positions, the drilling mud in the borehole 16 immediately exterior of the fluid-sampling tool 200 will be free to enter the sample chamber 213 by way of the ports 217 and 218 to fill the enlarged bore 216 above the seal 211.

It will be appreciated, therefore, that upon expansion of the free space within the axial bore 216 as the piston 219 moves upwardly in relation to the body 202, a discrete volume of the drilling mud will be inducted into the sampling chamber 213. It should be noted that during movement of the mandrel 201 between the fully-contracted position shown in FIGS. 6A and 6B and the first intermediate position shown in FIG. 7A, it is not essential that the seals 220 be engaged with the body 202 since the piston 219 will readily displace drilling mud from the chamber 213 by way of the ports 217 as fresh drilling mud is drawn into the sample chamber by way of the ports 218. As previously described with reference to FIG. 7A, the seals 222 on the valve member 221 will remain disengaged from the valve seat 215 until such time that the seals 220 on the piston member 219 are engaged with the upper seating surface 214. Once this occurs, as depicted in FIG. 7A, it will be recognized that a discrete and known volume of the drilling mud will then be entrapped within the sample chamber 213 as defined at that time between the lower part of the piston member 219 and the upper part of the valve member 221. Accordingly, any further upward movement of the mandrel 201 in relation to the body 202 must first result in an expansion of the sample chamber 213 and, therefore, a corresponding reduction of the pressure of the entrapped sample of the drilling mud as the mandrel moves between its first and second intermediate positions.

To understand the principles of the operation of the new and improved tool 200, it must be recognized that the physical characteristics of the mud sample entrapped in the sample chamber 213 will determine the sequence of events upon further upward movement of the mandrel 201 beyond the first intermediate position shown in FIG. 7A. First of all, those skilled in the art will appreciate that if only a gas were entrapped in the sample chamber 213, further upward travel of the mandrel 201 from its first intermediate position shown in FIG. 7A toward its second intermediate position would simply cause the entrapped gas to expand accordingly. Thus, in this unlikely situation, there would be no significant forces restraining continued upward travel of the mandrel 201. The pressure of the entrapped gas sample would merely be reduced in keeping with the general gas laws as the mandrel 201 moves between its first and second intermediate positions. The mandrel 201 would, of course, be easily moved to its fully-extended position as shown in FIG. 7B.

The situation just described will, of course, be significantly different where seating of the piston member 219 and closure of the valve member 221 traps a sample in the sample chamber 213 that is entirely a liquid. If this is the case, continued upward travel of the drill pipe 12 will simply be incapable of producing further extension of the mandrel 201 in relation to the body 202 beyond its first intermediate position unless the forces tending to fully extend the mandrel and the body are sufficient to reduce the pressure of the entrapped liquid sample in the chamber 213 to its saturation pressure at the existing ambient borehole temperature. Thus, for reasons which will subsequently be explained, in the preferred embodiment of the tool 200 the effective cross-sectional areas of the piston member 219 and the valve member 221 are purposely established to be certain that these forces are more than sufficient to fully extend the mandrel 201 in relation to the body 202.

As a result, in the operation of the tool 200 of the present invention, the presence of even a minor quantity of gas (e.g., something in the order of 2–3 percent or more) in the drilling mud will be sufficient to enable the mandrel 201 to be moved in relation to the body 202 from its fully-contracted position to its fully-extended position with a minimum degree of restraint. On the other hand, the substantial or total absence of gas in the drilling mud will result in an extreme force being required to move the inner and outer members 201 and 202 from their contracted position to their extended position.

To demonstrate that the degree of force required to extend the telescoping members 201 and 202 will be directly related to the gas content in the drilling mud, it has been found that the following equation defines these forces:

$$\text{Force} = (P_h \times A)\{1 - (V_s \times \%\text{Gas})/[(V_s \times \%\text{Gas}) + \Delta V_s]\} \quad \text{(Eq. 3)}$$

where,

P_h = hydrostatic pressure of the drilling mud at the depth at which the sample is being taken;

A = effective pressure area restraining movement of the telescoping members 201 and 202 to their fully-extended position (cross-sectional area of the piston seat 214 less the cross-sectional area of the valve seat 215);

V_s = volume of the sample chamber 213 when the tool 200 is positioned as shown in FIG. 6A;

%Gas = percentage, by volume, of gas in the drilling mud; and

ΔV_s = increase in volume of the sample chamber 213 as the tool 200 is extended from the intermediate position shown in FIG. 6A to the next intermediate position where the sample chamber is re-opened.

Accordingly, it will be seen from Equation 3 that for a given arrangement of the tool 200 and hydrostatic pressure, when the gas content in the drilling mud is zero, the force required to move the telescoping members 201 and 202 so as to re-open the sample chamber 213 will be directly related to the hydrostatic pressure, P_h, and the effective pressure area, A, and, therefore, quite high. On the other hand, since the volume, V_s, of the sample chamber 213 is preferably much larger than the expansion volume, ΔV_s, the bracketed fraction in Equation 3 will approach unity even with only minor percentages of gas in the drilling mud so that such

minor amounts of gas will substantially reduce the force F. In a preferred arrangement of the new and improved tool 200, the volume, V_s, of the sample chamber 213 was selected to be in the order of 100-times the expansion volume, ΔV_s. With typical hydrostatic pressures and an area, A, in the order of 3-sq. inches, the force, F, will be negligible whenever the gas content exceeds about 1–2 percent.

Turning now to FIGS. 8A and 8B, the two usual conditions to be experienced in operation of the tool 200 are graphically depicted. Taking the situation where there is a moderate to extreme percentage of gas in the drilling mud an observer at the surface viewing the weight indicator 22 will note a steady increase in the measured reading as upward movement of the drill string 11 progressively picks up the weight of the drill pipe 12 and the mandrel 201. Once the shoulder 207 is disengaged from the shoulder 208, the weight indicator 22 will show the entire weight of the kelly 24, the drill pipe 12, and the mandrel 201. This reading will, of course, remain substantially unchanged until the shoulder 205 engages the shoulder 206. From that point on, continued upward movement of the drill string 11 will again produce a continued increase in the reading shown on the indicator 22 until the drill bit 14 is picked up from the bottom of the borehole 16. The total reading shown on the weight indicator 22 will, of course, then be the full weight of the entire drill string 11.

As shown in FIG. 8A, the readings, W, of the weight indicator 22 in this situation when plotted against the upward travel, D, of the drill string 11 will be generally as graphically represented by the curve 223. These readings will, therefore, first follow an ascending sloping line, as at 224, until the shoulder 207 is first disengaged from the shoulder 208. The indicated weight, W, will then, as indicated at 225, remain constant over that portion of the tool stroke, d_1, where the shoulder 207 is moving away from the shoulder 208 and until the piston member 219 is sealed within the reduced bore portion 214 and the valve member 221 is seated on the valve seat 215. As previously mentioned, when a gas is trapped in the sample chamber 213 by closure of the valve member 221, the short travel, d_2, of the mandrel 201 between the two intermediate positions will be without significant restraint so that the reading on the weight indicator 22 will remain substantially unchanged (as graphically represented at 226 in FIG. 8A) until the sample chamber 213 is re-opened. Thereafter, as shown at 227, continued travel, d_3, of the mandrel 201 until it is halted (where the shoulder 205 engages the shoulder 206) will show an abrupt decrease as in the reading on the weight indicator 22. Once the total load on the hook 20 is reduced slightly to the weight of the kelly 24, the drill pipe 12 and the mandrel 201, the reading, W, on the weight indicator 22 will again remain constant until the shoulders 205 and 206 are engaged as the mandrel moves through its stroke, d_3, between its second intermediate position and its fully-extended position. As graphically represented at 228, upon engagement of the shoulders 205 and 206, further upward travel, D, of the drill pipe 12 will again produce an increasing reading, W, on the weight indicator 22 as the weight of the drill collars 13 is progressively added to that of the drill pipe already supported by the hook 20.

Accordingly, it will be recognized that if a sample of gas-containing mud is trapped in the sample chamber 213, the readings on the weight indicator 22 will generally be as represented by the curve 223 in FIG. 8A. The abrupt changes, as at 229, 227 and 230, in the curve 223 will clearly define the respective points during the testing operation when the shoulder 207 is disengaging from the shoulder 208, when the sample chamber 213 is re-opened, and when the shoulder 205 is engaging the shoulder 206. Those skilled in the art will appreciate, therefore, that readings such as those just described will be readily apparent at the surface since the respective weights of the drill pipe 12 on the one hand and those of the drill collars 13 and the drill bit 14 on the other hand are always known with a fair degree of accuracy.

As previously explained by reference to Equation 3, the situation is reversed when there is no gas in the drilling mud. As described, the mandrel will halt in its first intermediate position until the force acting on the telescoping members 201 and 202 is sufficient to expand the sample chamber 213. This will, of course, induce flashing of the entrapped liquid sample. In this event, once flashing of the liquid sample commences, the mandrel 201 will then be free to move upwardly beyond its second intermediate position and then toward its fully-extended position where the shoulder 205 engages the shoulder 206.

As shown in FIG. 8B, therefore, the readings, W, on the indicator 22 will generally vary as represented by the graph 231 where the entrapped sample is initially completely liquid but is ultimately reduced to its saturation pressure at the ambient borehole temperatures. Initial upward movement of the mandrel 201 toward its first intermediate position (FIG. 3) will again cause a steady increase in the reading, W, on the weight indicator 22 until the shoulder 207 disengages from the shoulder 208 (the point 232 on the curve 231). Then, there will be no further increase in weight (as shown by the line segment 233) until the piston member 219 is sealed within the bore 214 and the valve member 221 is seated on its associated seat 215 (the point 234 on the curve 231). Further upward travel, D, of the drill pipe 12 will then immediately produce a second steady increase of observed weight as shown at 235 on the curve 231.

Once the forces tending to further separate the mandrel 201 and the body 202 are sufficient to reduce the pressure of the entrapped liquid sample to its saturation pressure at the ambient temperature and flashing of the sample is commenced, as shown at 236 in FIG. 5, there will be no significant increase in the reading on the weight indicator 22 until the sample chamber 213 is reopened. Hereagain, there will then be an abrupt decrease, as at 237, in the reading, W, on the indicator 22 and then a steady reading, as at 238, until the shoulders 205 and 206 are engaged to begin imposing the combined weight of the drill collars 13 and the bit 14 onto the hook 20. This will again cause an increasing reading, W, on the indicator as shown at 239.

It will be noted, however, that when the telescoping members 201 and 202 move from their second extended position to their fully-extended position, there will be a sudden impact (as represented by the surge in force shown at 240 in FIG. 8B) as the shoulder 205 momentarily strikes the shoulder 206. It will be recognized that this sudden shock or impact will be caused by the momentary release of the forces tending to stretch the drill pipe 12 as the telescoped members 201 and 202

are moved between their two intermediate positions. This impact will, of course, produce a sudden shock force similar to that imposed by a typical drilling jar. Those skilled in the art will appreciate that such impacts are easily detected at the surface. Accordingly, in the operation of the new and improved tool 200 for practicing the methods of the present invention, the absence of gas in the drilling mud will produce a spaced succession of shocks or impacts which will signify there is little or no gas in the drilling mud. On the other hand, should these impacts cease, it will be known that gas has entered the borehole 16 and appropriate measures can be taken.

The preceding discriptions have assumed that the testing operations were conducted by elevating the drill pipe 12 in relation to the drilling platform 18. It will be appreciated, however, that identical reactions will be obtained where the drill pipe 12 is maintained at about the same longitudinal position as the drill string 11 is being rotated. If this is the situation, it will be recognized that as the drill bit 14 continues to cut away at the bottom of the borehole 16, the weight of the drill collars 13 and the drill bit will tend to carry the body 202 downwardly in relation to the longitudinally-stationary mandrel 201 and the piston member 219 and the valve member 221. Thus, the same results as previously described will be obtained.

In other words, downward movement of the drill bit 14 will progressively carry the body 202 downwardly in relation to the longitudinally-stationary piston member 219 and the valve member 221 so that the sample chamber 213 will ultimately be closed. Thereafter, the weight readings, W, which will be registered by the indicator 22 will again be determined by the nature of state of the entrapped fluid within the sample chamber 213. Stated another way, since the combined weight of the drill collars 13 and the drill bit 14 represent the maximum force which can be effective for moving the testing tool 200 to its fully-extended position, the above detailed descriptions are equally applicable regardless of whether it is the mandrel 201 which is being moved upwardly in relation to the longitudinally-stationary body 202 or it is the body which is being moved downwardly in relation to the longitudinally-stationary mandrel. In either case, easily-recognized surface indications will be provided to warn the observer of an impending blowout.

From the foregoing descriptions of the new and improved testing tool 200, it will be appreciated from FIGS. 8A and 8B that an observer at the surface can readily deduce from the changes in the weight readings, W, on the indicator 22 in association with upward movement of the drill string 11 whether or not gas is then present in the borehole 16 in the vicinity of the drill collars 13. Thus, a simple "go-no go" type of test can be readily performed during the course of the drilling operation merely by elevating the drill string 11 a sufficient distance to fully extend the telescoping members 201 and 202 of the testing tool 200 and observing the resulting effects as visibly displayed on the weight indicator 22. A test of this nature can, of course, be rapidly conducted with no appreciable interruption of the drilling operation. Moreover, if necessary, several tests can be conducted for verification by simply lowering the drill string 11 to expel the first sample and reposition the various elements of the testing tool 200.

It should be noted that the new and improved testing tool 200 is also capable of performing the above-described test without raising the drill string 11. Thus, at any time during a drilling operation, if the drill string 11 is slacked off to be certain that the telescoping members 201 and 202 of the testing tool 200 are in their respective fully-telescoped positions, as the drilling operation commences the drill bit 14 will progressively deepen the borehole 16 to move the telescoping members toward their extended positions. An observer can, therefore, note the time interval required for the telescoped members 201 and 202 of the testing tool 200 to move to the point where the piston member 219 and the valve member 221 is first seated. This time interval can, of course, be readily determined at the surface since the pronounced cessation of the increasing weight indications which occurs once the full weight of the drill pipe 12 is suspended on the hook 20 will identify when the telescoping members 201 and 202 first start moving and the next change in the weight indication will show when the piston member 219 and the valve member 221 are first seated.

It should be noted that the piston seals 220 are purposely oriented to preferably withstand a pressure differential acting downwardly. Similarly, the valve seals 222 are also oriented to preferably seal best against a pressure differential acting upwardly. Thus, when the sampling chamber 213 is closed and the mandrel 201 is moved upwardly, the chamber will be expanded to achieve a reduction in the pressure of the entrapped sample without leakage past the seals 220 and 222. Conversely, by orienting the seals 220 and 222 as depicted, downward movement of the mandrel 201 will not tend to sealingly engage the seals with the body 202. This will, of course, facilitate returning the telescoped members 201 and 202 to their fully-retracted position.

Accordingly, it will be appreciated that the present invention has provided new and improved methods and apparatus for detecting the entry or presence of gas in a borehole being excavated and signaling this to the surface. In practicing the methods of the present invention, a discrete sample of drilling mud from the borehole is periodically trapped within an expansible sampling chamber defined between a pair of telescoping members coupled to a drill string adjacent to the drill bit. By moving the drill string so as to expand the sampling chamber, the pressure of the entrapped sample is reduced to at least the saturation pressure of a gas-containing drilling mud at the borehole ambient temperature. By measuring the force required to expand the sampling chamber, the presence or absence of formation gas in the drilling fluid can be determined; and, if desired, these force measurements may be used to derive quantitative measurements which are representative of the percentage of gas entrained in the discrete sample.

In the representative embodiments of the apparatus of the present invention disclosed herein, one or more unique sampling devices are arranged between the upper and lower telescoping members of a typical slip joint which is tandemly connected in the drill string preferably a short distance above the drill bit. Each of these fluid samplers includes telescoping piston and chamber members defining an enclosed sample chamber which is expanded in response to extension of the slip joint members. Valve means are cooperatively ar-

ranged with each of the sampling devices for admitting a predetermined volume of drilling mud into the sample chambers each time the slip joint is extended.

While only particular embodiments of the present invention and modes of practicing the 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 determining whether formation gas is present in the drilling mud in a borehole being excavated by a drill bit coupled to a drill string having upper and lower portions operatively arranged for movement relative to one another between spaced positions and comprising the steps of:

entrapping a sample of said drilling mud from a selected depth in said borehole in an expansible sampling chamber coupled between said upper and lower drill string portions and adapted for expansion upon movement of one of said drill string portions relative to the other of said drill string portions;

moving one of said drill string portions relative to the other of said drill string portions to expand said sampling chamber for reducing the pressure of said mud sample to at least the saturation pressure of a gas-containing drilling mud at the ambient borehole temperature; and

obtaining an indication representative of the difference between the force required to support said upper drill string portion and the force required to expand said sampling chamber for detecting the presence or absence of formation gas in said mud sample.

2. A method for determining whether formation gas is present in the drilling mud in a borehole being excavated by a drill bit coupled to a drill string having upper and lower portions operatively arranged for movement relative to one another between spaced positions and comprising the steps of:

entrapping a sample of said drilling mud from a selected depth in said borehole in an expansible sampling chamber coupled between said upper and lower drill string portions and adapted for expansion upon movement of one of said drill string portions relative to the other of said drill string portions;

moving one of said drill string portions relative to the other of said drill string portions to expand said sampling chamber for reducing the pressure of said mud sample to at least the saturation pressure of a gas-containing drilling mud at the ambient borehole temperature;

moving said one drill string portion relative to said other drill string portion for relieving said mud sample pressure; and

obtaining an indication representative of the differential between the force required to expand said sampling chamber and the force required to relieve said mud sample pressure for detecting the presence or absence of formation gas in said mud sample.

3. A method for determining whether formation gas is present in the drilling mud in a borehole being excavated by a drill bit coupled to a drill string having upper and lower portions operatively arranged for movement relative to one another between spaced positions and comprising the steps of:

entrapping a sample of said drilling mud from a selected depth in said borehole in an expansible sampling chamber coupled between said upper and lower drill string portions and adapted for expansion upon movement of one of said drill string portions relative to the other of said drill string portions;

moving one of said drill string portions relative to the other of said drill string portions to expand said sampling chamber for reducing the pressure of said mud sample to at least the saturation pressure of a gas-containing drilling mud at the ambient borehole temperature; and

measuring the force required to expand said sampling chamber for detecting the presence or absence of formation gas in said mud sample.

4. The method of claim 3 further including the steps of:

moving one of said drill string portions relative to the other of said drill string portions to contract said sampling chamber for expelling said mud sample;

entrapping a second sample of said drilling mud from said selected depth in said sampling chamber;

moving one of said drill string portions relative to the other of said drill string portions to re-expand said sampling chamber for reducing the pressure of said second mud sample to at least said saturation pressure; and

measuring the force required to re-expand said sampling chamber for verifying the force measurement obtained from expansion of said first mud sample.

5. The method of claim 3 wherein said one drill string portion is said upper drill string portion and movement thereof is accomplished by elevating said upper drill string portion.

6. The method of claim 3 wherein said one drill string portion is said lower drill string portion and movement thereof is accomplished by continuing to excavate said borehole with said drill bit for lowering said lower drill string portion in relation to said upper drill string portion.

7. A method for determining whether formation gas is present in the drilling mud in a borehole being excavated by a drill bit coupled to a drill string having upper and lower portions telescopically arranged together for longitudinal movement relative to one another between spaced positions and comprising the steps of:

entrapping a sample of said drilling mud from a selected depth in said borehole in an expansible sampling chamber operatively arranged between said drill string portions and adapted for expansion upon longitudinal movement of one of said drill string portions from a first of said spaced positions to a second of said spaced positions relative to the other of said drill string portions;

measuring the force required to support said drill string in said borehole while said drill string portions are in their said first position;

moving one of said drill string portions relative to the other of said drill string portions and toward the second of said spaced positions to expand said sampling chamber for reducing the pressure of said

mud sample to at least the saturation pressure of a gas-containing drilling mud at the ambient borehole temperature;

measuring the force required to support said drill string in said borehole while said drill string portions are in their said second spaced position; and

comparing said force measurements for determining whether formation gas is present in said drilling mud.

8. The method of claim 7 further including the steps of:

moving one of said drill string portions relative to the other of said drill string portions to contract said sampling chamber for expelling said mud sample;

entrapping a second sample of said drilling mud from said selected depth in said sampling chamber;

remeasuring the force required to support said drill string in said borehole while said drill string portions are again in their said first position;

moving one of said drill string portions relative to the other of said drill string portions to re-expand said sampling chamber for reducing the pressure of said second mud sample to at least said saturation pressure;

remeasuring the force required to support said drill string in said borehole while said drill string portions are in their said second spaced position; and

comparing said force remeasurements for verifying the determination obtained by comparison of said force measurements.

9. The method of claim 7 wherein said one drill string portion is said upper drill string portion and movement thereof is accomplished by elevating said upper drill string portion.

10. The method of claim 7 wherein said one drill string portion is said lower drill string portion and movement thereof is accomplished by continuing to excavate said borehole with said drill bit for lowering said lower drill string portion in relation to said upper drill string portion.

11. A method for determining whether formation gas is present in the drilling mud in a borehold being excavated by a drill bit coupled to a drill string having upper and lower portions telescopically arranged together for longitudinal movement relative to one another between spaced positions and comprising the steps of:

entrapping a sample of said drilling mud from a selected depth in said borehole in an expansible sampling chamber operatively arranged between said drill string portions and adapted for expansion upon longitudinal movement of one of said drill string portions from a first of said spaced positions to a second of said spaced positions relative to the other of said drill string portions;

measuring the force required to support said drill string in said borehole while said drill string portions are in their said first position;

moving one of said drill string portions relative to the other of said drill string portions and toward the second of said spaced positions to expand said sampling chamber for reducing the pressure of said mud sample to at least the saturation pressure of a gas-containing drilling mud at the ambient borehole temperature;

measuring the force required to support said drill string in said borehole while said drill string portions are in their said second spaced position; and

determining the percentage of formation gas contained in said drilling mud from the following equation:

$$\% \text{ gas (by volume)} = (\Delta d/d_2)[(W_{max} - W)/W] \times 100\%$$

where,

Δd = longitudinal displacement of said drill string portions between their said first and second positions;

d_2 = maximum possible longitudinal displacement of said drill string portions;

W = the difference between said force measurements; and

W_{max} = the product of said borehole depth, the density of said drilling mud and the cross-sectional area of said sampling chamber.

12. The method of claim 11 wherein said one drill string portion is said upper drill string portion and movement thereof is accomplished by elevating said upper drill string portion.

13. The method of claim 11 wherein said one drill string portion is said lower drill string portion and movement thereof is accomplished by continuing to excavate said borehole with said drill bit for lowering said lower drill string portion in relation to said upper drill string portion.

14. A method for determining whether formation gas is present in a borehole being excavated by a drill bit coupled to a drill string having telescoped piston and chamber members cooperatively arranged thereon for defining therebetween an expansible sampling chamber and adapted for longitudinal movement relative to one another between a contracted position where said sampling chamber has a reduced volume and an extended position where said sampling chamber has an increased volume and comprising the steps of:

moving one of said telescoped members relative to the other of said telescoped members from said contracted position toward said extended position for inducting a discrete volume of drilling mud into said sampling chamber;

while said telescoped members are between their said positions, closing said sampling chamber for entrapping a sample of said drilling mud in said sampling chamber;

measuring the force required to support said drill string in said borehole once said mud sample has been entrapped in said sampling chamber;

moving said one telescoped member relative to said other telescoped member and further toward said extended position to expand said sampling chamber for reducing the pressure of said mud sample to at least the saturation pressure of a gas-containing drilling mud at the ambient borehole temperature;

measuring the force required to support said drill string in said borehole after said entrapped mud sample has been expanded in said sampling chamber; and

correlating said force measurements for determining whether formation gas is present in said mud sample.

15. The method of claim 14 wherein said sampling chamber is expanded by elevating said drill string to

raise said one telescoped member toward said extended position.

16. The method of claim 14 wherein said sampling chamber is expanded by continuing to excavate said borehole with said drill bit for lowering said one telescoped member toward said extended position.

17. A method for detecting whether formation gas is present in a borehole being excavated by a drill bit coupled to a drill string having telescoped piston and chamber members cooperatively arranged thereon for defining therebetween an expansible sampling chamber and adapted for longitudinal movement relative to one another between a contracted position where said sampling chamber has a reduced volume, first and second intermediate positions where said sampling chamber has an increased volume, and an extended position where said piston member is removed from said sampling chamber and opposite shoulders on said telescoped members are co-engaged, and comprising the steps of:

moving one of said telescoped members relative to the other of said telescoped members from said contracted position toward said first intermediate position for inducting a discrete volume of drilling mud into said sampling chamber;

while said telescoped members are in their said first intermediate position, closing said sampling chamber for entrapping a sample of said drilling mud in said sampling chamber;

once said mud sample has been entrapped in said sampling chamber, moving said one telescoped member relative to said other telescoped member to said second intermediate position to expand said sampling chamber for reducing the pressure of said mud sample to at least the saturation pressure of a gas-containing drilling mud at the ambient borehole temperature; and,

after said entrapped mud sample has been expanded in said sampling chamber, moving said one telescoped member relative to said other telescoped member to said extended position to remove said piston member from said sampling chamber and bring said opposed shoulders together with a force representative of the presence or absence of formation gas in said mud sample.

18. The method of claim 17 wherein said telescoped members are moved relative to one another by elevating said drill string to raise said one telescoped member toward said extended position.

19. The method of claim 17 wherein said telescoped members are moved relative to one another by continuing to excavate said borehole with said drill bit for lowering said one telescoped member toward said extended position.

20. the method of claim 17 wherein the force required to move said one telescoped member for bringing said opposed shoulders together is expressed by the equation:

$$\text{Force} = (P_h \times A)\{1 - (V_s \times \%\text{gas})/[(V_s \times \%\text{gas}) + \Delta V_s]\}$$ *where,*

P_h = hydrostatic pressure of said drilling mud in said borehole adjacent to said sampling chamber;

A = effective pressure area restraining movement of said one telescoped member relative to said other telescoped member;

V_s = volume of said sampling chamber when said telescoped members are in their said first intermediate position;

ΔV_s = increase in volume of said sampling chamber resulting from expansion thereof; and

%gas = percentage, by volume, of formation gas in said mud sample.

21. Apparatus adapted for determining whether formation gas is present in the drilling mud in a borehold being excavated and comprising:

a drill string having a drill bit dependently coupled thereto and including inner and outer telescoped members tandemly connected therein and cooperatively arranged for movement relative to one another between spaced positions;

first means cooperatively arranged between said telescoped members and defining an expansible fluid chamber adapted to be expanded from a selected volume to progressively-larger volumes in response to movement of said telescoped members from one of their said spaced positions toward another of their said spaced positions;

second means cooperatively arranged between said telescoped members and adapted for sequentially admitting a sample of drilling mud into said fluid chamber as said telescoped members are moved away from their said one position and then entrapping that sample in said fluid chamber as said telescoped members are moved toward their said other position; and

third means for obtaining an indication representative of the force required for moving said telescoped members further away from their said one position after a mud sample is entrapped in said fluid chamber.

22. The apparatus of claim 21 wherein said first means include a body associated with one of said telescoped members and having an internal bore with a reduced-diameter portion and an enlarged-diameter portion, and a piston associated with the other of said telescoped members and arranged in said internal bore for defining therein said fluid chamber and movable therein from said reduced-diameter bore portion into said enlarged -diameter bore portion in response to said movement of said telescoped members further away from their said one position.

23. The apparatus of claim 22 wherein said second means include passage means cooperatively arranged between said fluid chamber and the exterior of said body for admitting drilling mud into said fluid chamber, and valve means cooperatively associated with said passage means and movable between a passage-opening position when said telescoped members are in their said one position and a passage-closing position in response to movement of said telescoped members toward their said other position before said piston is moved out of said reduced-diameter bore portion.

24. The apparatus of claim 23 wherein said third means include first and second opposed shoulders respectively associated with said inner and outer telescoped members for engagement with a force related to the load on said drill string required to move said telescoped members further away from their said one position.

25. The apparatus of claim 21 wherein said first means include a body associated with one of said telescoped members and having an internal bore, and a pis-

ton associated with the other of said telescoped members and movably arranged in said internal bore for defining therein said fluid chamber.

26. The apparatus of claim **25** wherein said second means include passage means cooperatively arranged between said fluid chamber and the exterior of said body for admitting drilling mud into said fluid chamber, and valve means cooperatively associated with said passage means and movable between a passage-opening position when said telescoped members are in their said one position and a passage-closing position in response to movement of said telescoped members toward their said other position.

27. The apparatus of claim **26** wherein said third means include force-responsive means at the surface and adapted for measuring varying loads on said drill string as said telescoped members are moved between their said positions.

28. The apparatus of claim **21** wherein said first means include sealing means cooperatively mounted on said inner telescoped members and operatively associated with said outer telescoped member for defining said fluid chamber therebetween.

29. The apparatus of claim **28** wherein said second means include passage means defined between said telescoped members for admitting drilling mud into said fluid chamber, a fluid seal cooperatively arranged on one of said telescoped members in said passage means, and a sealing surface cooperatively arranged on the other of said telescoped members in said passage means and adapted for sealing engagement with said fluid seal to close said passage means upon movement of said telescoped members toward their said other position.

30. The apparatus of claim **29** wherein said third means include force-responsive means at the surface and adapted for measuring varying loads on said drill string as said telescoped members are moved between their said positions.

31. Apparatus adapted for determining whether formation gas is present in the drilling mud in a borehole being excavated and comprising:

a drill string having a drill bit dependently coupled thereto and including inner and outer telescoped members tandemly connected therein and cooperatively arranged for upward and downward movements relative to one another between longitudinally-spaced positions;

fluid-sampling means including a body operatively associated with one of said telescoped members and having an internal bore, a piston operatively associated with the other of said telescoped members and movably disposed in said internal bore of said body for defining therebetween an expansible fluid chamber adapted to be expanded from a selected reduced volume when said telescoped members are in a relatively-contracted position to a selected increased volume when said telescoped members are in a relatively-extended position, passage means between said fluid chamber and the exterior of said fluid-sampling means, and valve means cooperatively arranged with said fluid-sampling means and selectively operable in response to relative movements between said body and said piston for admitting drilling mud through said passage means as said fluid chamber is expanded from said reduced volume to a selected intermediate volume and for blocking said passage means as said fluid chamber is expanded from said intermediate volume toward said increased volume for reducing the pressure of a mud sample entrapped in said fluid chamber; and

force-responsive means adapted for providing an indication at the surface of the force required for expanding said fluid chamber beyond its said intermediate volume to indicate whether gas is present in a mud sample entrapped in said fluid chamber.

32. The apparatus of claim **31** wherein said body and piston are separate members; and further including means coupling said body to said one telescoped member; and means coupling said piston to said other telescoped member.

33. The apparatus of claim **31** wherein said body and piston are separate members respectively disposed exterior of said telescoped members; and further including means coupling said body to said one telescoped member; and means coupling said piston to said other telescoped member.

34. The apparatus of claim **31** wherein said force-responsive means include a weight indicator coupled to said drill string and operatively arranged to provide a first weight measurement of said drill string as said fluid chamber is being expanded from said reduced volume to said intermediate volume and to provide a second weight measurement of said drill string as said fluid chamber is being expanded from said intermediate volume toward said increased volume.

35. The apparatus of claim **34** further including means at the surface for determining the relative positions of said body and said piston so that the percentage of gas by volume in a mud sample entrapped in said fluid chamber can be determined by the equation:

$$\% \text{ gas (by volume)} = (\Delta d/d_2)[(W_{max} - W] \times 100\%$$

where,

Δd = longitudinal displacement of said telescoped members between their position defining said intermediate volume where said first load measurement is obtained and their position where said second load measurement is obtained;

d_2 = maximum longitudinal displacement of said telescoped members between their position defining said intermediate volume and their said relatively-extended position;

W = the difference between said first and second weight measurements; and

W_{max} = product of the borehole depth, the density of the drilling mud in the borehole, and the cross-sectional area of said piston.

36. The apparatus of claim **34** further including means at the surface for determining when said fluid chamber is fully expanded so that the percentage of gas by volume in a mud sample entrapped in said fluid chamber can be determined by the equation:

$$\% \text{ gas (by volume)} = (d_1 1/d_2)\ [(P_h \times A)/(W_2 - W_1)] - 1 \times 100\%$$

where,

d_1 = longitudinal displacement of said telescoped members between their said relatively-contracted position and their position defining said intermediate volume;

d_2 = maximum longitudinal displacement of said telescoped members between their position defining

said intermediate volume and their said relatively-extended position;

P_h = hydrostatic pressure of the drilling mud at the borehole depth at which a mud sample is being taken;

A = cross-sectional area of said piston;

W_1 = weight indication at the time a mud sample is being inducted into said fluid chamber; and

W_2 = weight indication when said telescoped members first reach their said relatively-extended position.

37. The apparatus of claim 31 wherein said valve means include a valve seat defined in said passage means, a valve member movably disposed in said passage means and cooperatively arranged for movement into and out of seating engagement with said valve seat, and actuating means operative upon relative movements between said body and said piston for moving said valve member into seating engagement with said valve seat as said fluid chamber is expanded beyond said intermediate volume.

38. The apparatus of claim 31 wherein said valve means include a valve seat defined in said passage means, a valve member movably disposed in said passage means and cooperatively arranged for movement into and out of seating engagement with said valve seat, and actuating means including first means normally biasing said valve member toward seating engagement with said valve seat, an actuating member operatively arranged on said piston for retaining said valve member out of seating engagement with said valve seat until said body and piston are relatively positioned where said fluid chamber is at its said intermediate volume, and second means normally biasing said actuating member against said valve member until said body and piston are relatively positioned where said fluid chamber has a volume equal to or greater than said intermediate volume.

39. The apparatus of claim 31 wherein said valve means include a fluid seal cooperatively arranged on one of said telescoped members in said passage means and a sealing surface cooperatively arranged on the other of said telescoped members in said passage means and adapted for sealing engagement with said fluid seal to close said passage means upon movement of said telescoped members for expanding said fluid chamber from said intermediate volume toward said increased volume.

40. Apparatus adapted for determining whether formation gas is present in the drilling mud in a borehole being excavated and comprising:

a drill string having a drill bit dependently coupled thereto and including inner and outer telescoped members tandemly connected therein and cooperatively arranged for upward and downward movements relative to one another between longitudinally-spaced positions;

fluid-sampling means including means cooperatively arranged between said telescoped members for defining therebetween an expansible fluid chamber adapted to be expanded from a reduced volume when said telescoped members are in a contracted position to an increased volume when said telescoped members are in an intermediate position and adapted to be opened when said telescoped members are in an extended position, passage means between said fluid chamber and the exterior of said fluid-sampling means, and valve means cooperatively arranged on said telescoped members and responsive to relative movements therebetween for admitting drilling mud through said passage means as said fluid chamber is expanded from said reduced volume to a selected intermediate volume and for blocking said passage means as said fluid chamber is expanded from said intermediate volume toward said increased volume for reducing the pressure of a mud sample entrapped in said fluid chamber; and

means adapted for providing indications at the surface to determine the differential between the force required to move said telescoped members between their said contracted and intermediate positions and the force required to move said telescoped members between their said intermediate and extended positions to indicate whether gas is present in a mud sample entrapped in said fluid chamber.

41. The apparatus of claim 40 wherein said means defining a fluid chamber include a longitudinal bore in said outer telescoped member having a reduced-diameter portion and an enlarged-diameter portion, and a piston member arranged on said inner telescoped member and disposed within said longitudinal bore for movement in said reduced-diameter bore portion as said telescoped members are moved from their said contracted position to their said intermediate position and for movement in said enlarged-diameter bore portion as said telescoped members are moved from their said intermediate position to their said extended position.

42. The apparatus of claim 40 wherein said indication-providing means include first and second opposed shoulders respectively arranged between said telescoped members and adapted for co-engagement with a force representative of the presence or absence of formation gas in a mud sample in said fluid chamber upon movement of said telescoped members to their said extended position.

43. The apparatus of claim 40 wherein said indication-providing means include a weight indicator coupled to said drill string and operatively arranged to provide a first weight measurement of said drill string as said fluid chamber is being expanded from said reduced volume to said intermediate volume and to provide a second weight measurement of said drill string as said fluid chamber is being expanded from said intermediate volume toward said increased volume.

44. Apparatus adapted for determining whether formation gas is present in the drilling mud in a borehole being excavated and comprising:

a drill string having a drill bit dependently coupled thereto;

fluid-sampling means cooperatively arranged in said drill string and including a tubular body tandemly connected to one portion of said drill string and having a longitudinal bore including upper and lower enlarged-diameter bore portions separated at their adjacent ends by a reduced-diameter bore portion, passage means providing fluid communication between the exterior of said body and at least one of said enlarged-diameter bore portions, a tubular mandrel tandemly connected to another portion of said drill string and telescopically arranged in said body for longitudinal movement

therein between longitudinally-spaced upper and lower positions, piston means cooperatively arranged on said mandrel for movement between the other end of said one enlarged-diameter bore portion and said adjacent end thereof for inducting a sample of drilling mud therein as said telescoped members are moved from one of said upper and lower positions to a first intermediate position where said piston means enter said reduced-diameter portion and become sealingly engaged therein, and valve means cooperatively arranged between said telescoped members for fluidly sealing said other end of said one enlarged-diameter bore portion as said telescoped members are moved between said first intermediate position and a second intermediate position where said piston means leave said reduced-diameter bore portion and enter the other of said enlarged-diameter bore portions to expand a sample of drilling mud inducted into said one enlarged-diameter bore portion; and

means adapted for providing indications at the surface representative of the force required to move said telescoped members between said first and second intermediate positions to indicate whether gas is present in a sample of drilling mud inducted into said one enlarged-diameter bore portion and released into said other enlarged-diameter bore portion as said telescoped members are moved from said second intermediate position to the other of said upper and lower positions.

45. The apparatus of claim **44** wherein said indication-providing means include first and second opposed shoulders respectively arranged on said body and said mandrel and adapted for impacting with a force representative of the presence or absence of formation gas in a sample of drilling mud inducted into said one enlarged-diameter bore portion.

46. The apparatus of claim **44** wherein said indication-providing means include a weight indicator coupled to said drill string and operatively arranged to provide at least one weight measurement of said drill string as said telescoped members are moved between said first and second intermediate positions.

47. The apparatus of claim **44** wherein said indication-providing means include a weight indicator coupled to said drill string and operatively arranged to provide a first weight measurement of said drill string as said telescoped members are moved between said first and second intermediate positions and a second weight measurement of said drill string as said telescoped members are moved between said second intermediate position and said other position.

48. The apparatus of claim **44** wherein said valve means include a valve seat cooperatively arranged in said longitudinal bore in said passage means, and a valve member cooperatively arranged on said mandrel for seating engagement with said valve seat at least as long as said telescoped members are moved between said first and second intermediate positions.

49. The apparatus of calim **48** wherein the cross-sectional area of said piston means is greater than the cross-sectional area of said valve member.

50. The apparatus of claim **44** wherein said passage means also provide fluid communication between said body exterior and said other enlarged-diameter bore portion.

51. The apparatus of claim **50** wherein said piston means include an enlarged shoulder on said mandrel, and sealing means on said enlarged shoulder cooperatively arranged to be sealingly engaged only with said reduced-diameter bore portion.

52. The apparatus of claim **51** wherein said sealing means include a plurality of chevron shaped seals cooperatively arranged to sealingly engage said reduced-diameter bore portion only as said telescoped members are being moved from said first intermediate position to said second intermediate position.

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