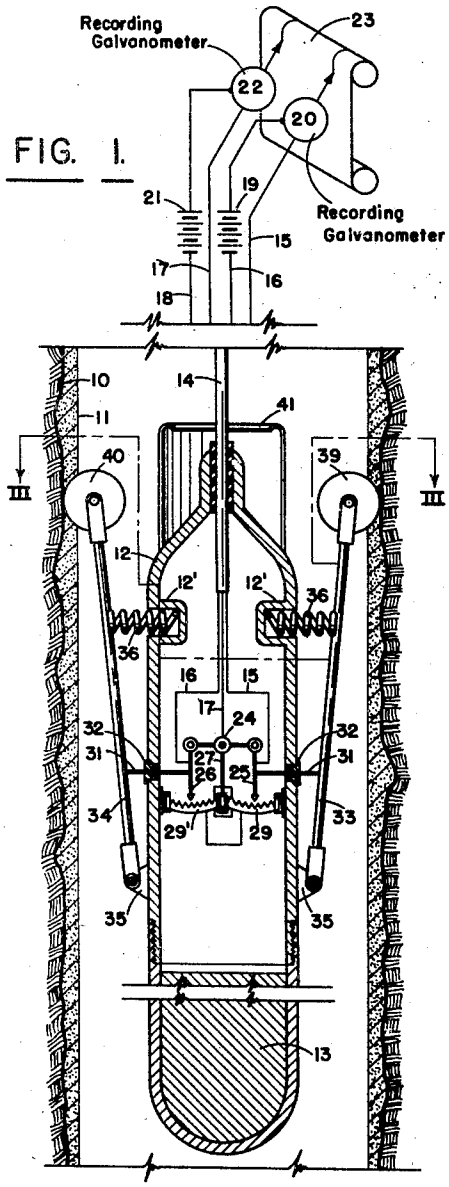
Feb. 21, 1950 T. A. HUBER ET AL 2,497,990

APPARATUS FOR LOGGING BOREHOLES

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FIG. 1.



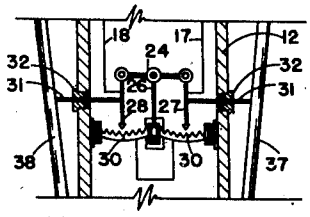


FIG. 2.

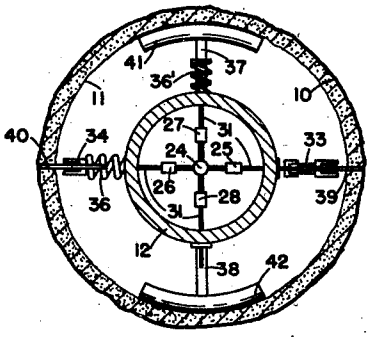


FIG. 3.

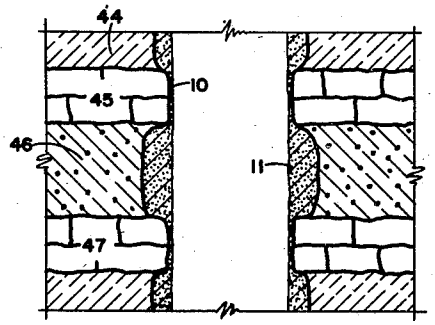


FIG. 4.

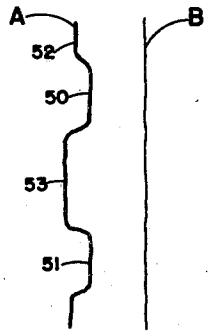


FIG. 5.

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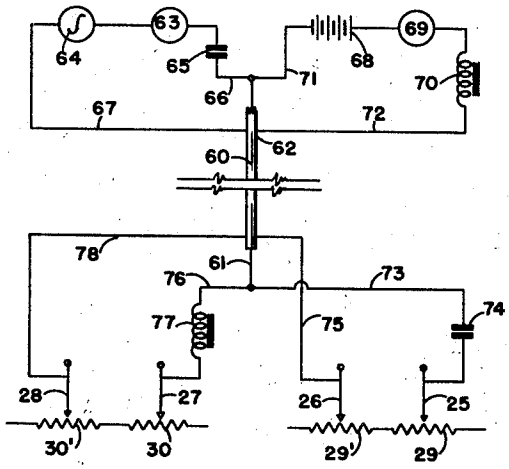


FIG. 6.

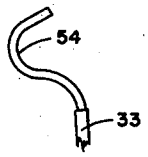


FIG. 9.

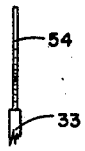


FIG. 9A

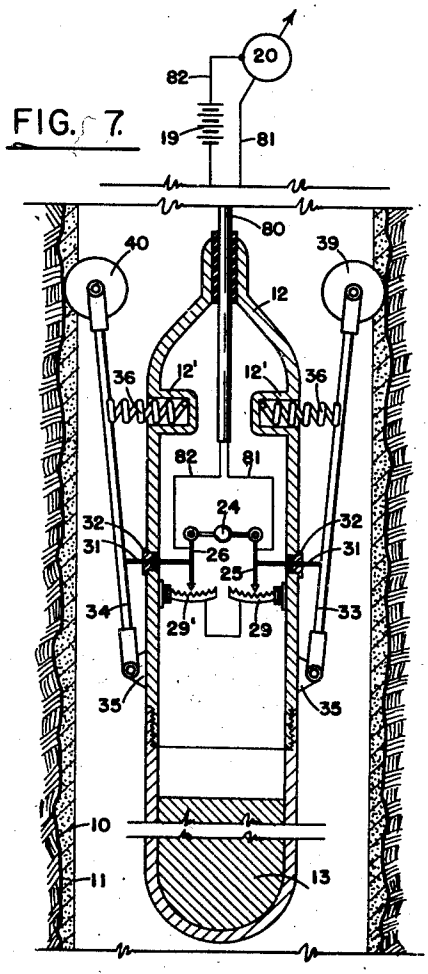


FIG. 7.

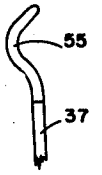


FIG. 10.

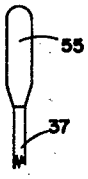


FIG. 10A.

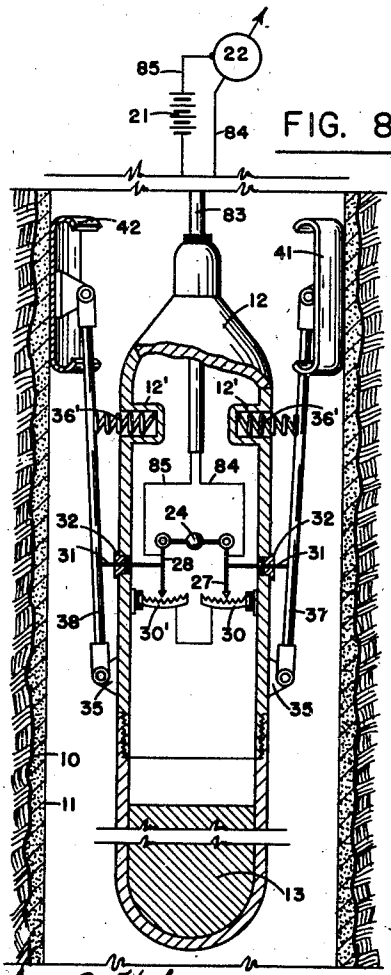


FIG. 8.

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Patented Feb. 21, 1950

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UNITED STATES PATENT OFFICE

2,497,990

APPARATUS FOR LOGGING BOREHOLES

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Application November 30, 1946, Serial No. 713,202

1 Claim. (Cl. 33—174)

1

The present invention is directed to apparatus for logging boreholes. More particularly, the present invention is directed to apparatus for determining the thickness of the mud cake deposited on the wall of holes produced by drilling with the rotary drilling method.

The present application is a continuation-in-part of our application, Serial No. 610,332, filed August 11, 1945 which is now abandoned.

The majority of deep boreholes produced for the purpose of recovering fluids from subsurface reservoirs are obtained by drilling with the rotary drilling method. This drilling method may be described briefly as involving the rotation of a drill stem carrying a drill bit on its lower end while a stream of drilling fluid is continuously forced down the drill stem to the drill bit and thence into the borehole and upwardly in the annular space between the drill stem and the wall of the borehole. The drilling fluid conveniently used is a thixotropic suspension serving several purposes. The drilling fluid serves to cool the drill bit, it acts as a lubricant in the borehole, it serves to carry cuttings from the bottom of the borehole to the surface, it forms a mud sheath or filter cake on the wall of the hole to reduce or eliminate the loss of drilling fluid from the hole and the hydrostatic pressure exerted by the drilling fluid prevents the flow of gas or oil from formations into the borehole.

Recently there has been a considerable interest in determining the diameter of boreholes produced by rotary drilling methods. The Kinley U. S. Patent 2,102,080, issued December 14, 1937, and Kinley et al. U. S. Patent 2,267,110, issued December 23, 1941, are directed to devices for measuring the diametric variations in a borehole. The devices disclosed by these patents are provided with spring actuated arms and suitable recording mechanisms so that the arms are thrust outwardly and the lateral displacement of the ends thereof recorded. These devices have been found useful in the drilling and completion of wells. For example, it has been found that when boreholes are drilling through unconsolidated formations, the hole may be much larger than the drill bit. If the diametric variations of the borehole are determined before a completion operation, such as cementing or setting a packer, a more satisfactory well completion may be obtained.

The present invention is directed to the logging of boreholes by determining the variations in the thickness of the mud sheath with the depth of the hole. The log obtained in the practice of

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the present invention may be employed for determining the log of the more permeable formations penetrated by the borehole. In conventional rotary drilling operations, liquid from the drilling fluid enters the formations penetrated by the drill bit and as the liquid passes from the borehole, solids from the drilling fluid are deposited on the wall of the hole as a filter cake. If a formation is substantially impermeable only a small amount of liquid phase passes into the formation, and the thickness of the cake adjacent the formation is negligible, but if a formation is permeable a filter cake of substantial thickness may be built on the wall of the hole, the thickness of the cake being a function of the permeability of the formation. The log of the present invention may accordingly be used to determine the location of the more permeable formations in the well. The log of the present invention may also be used in conjunction with completion operations in a well, such as the setting of packers or the cementing of cement casings wherein an advance knowledge of the thickness of the filter cake in the borehole allows a more satisfactory choice of the packer employed or of the steps to be used in preparing the borehole.

The present invention may be characterized briefly as involving the measurement of the radius of the exposed face of the mud sheath of a borehole and the measurement of the radius of the hole defined by the subsurface formations or the true radius of the hole and using these measurements to produce a log which indicates the variations in the thickness of the mud sheath with the depth of the hole. The method is conveniently carried out by passing along the bore of the hole a plurality of pairs of arms with each pair having ends biased outwardly. It is necessary for at least one pair of arms to have a suitable configuration and bias to force a surface of each arm composing the pair through the mud sheath of the hole so that these surfaces bear directly against the faces of the original formations defining the true diameter of the borehole. It is further necessary that at least another pair of arms be given the proper configuration and bias so that a surface of each arm of the pair bears against the exposed face of the mud sheath deposited along the borehole and does not cut into the mud sheath to any appreciable extent. It may be pointed out that the mud sheath in a borehole commonly offers considerable resistance but may be penetrated in a manner somewhat analogous to the penetration

of surface soil by a plow, while the original subsurface formations, even those which are relatively porous, offer a great deal of resistance to penetration. Accordingly, the provision of a pair of arms with the free end of each arm presenting a small surface to the mud sheath and biased by a strong spring allows the penetration of the mud sheath without the penetration of original subsurface formations while the arrangement of a pair of arms with the free end of each arm presenting a relatively large surface to the mud sheath and biased with relatively weak springs allows the diameter of the exposed face of the mud sheath to be obtained.

It will be understood that the method of the present invention may be practiced by employing a variety of mechanisms. In the drawing, modifications of equipment satisfactory for the practice of the invention are shown by way of example. It is to be understood that the invention is by no means limited to the employment of the particular embodiments disclosed.

In the drawing

Fig. 1 is an elevational view, with parts in section, of an embodiment adapted for obtaining a log from which the thickness of the mud cake of the borehole may be determined;

Fig. 2 is a fragmentary view, with parts in section, of a portion of the device of Fig. 1 taken at right angles to the view of Fig. 1;

Fig. 3 is an other view of the embodiment of Fig. 1 taken along section line III—III of Fig. 1;

Fig. 4 is a section through a well showing an arrangement of permeable and substantially impermeable strata and variations in thickness of mud cake adjacent said strata;

Fig. 5 is the type of a log obtained when using the device of Figs. 1, 2, and 3 and traversing that portion of the borehole shown in Fig. 4;

Fig. 6 is an embodiment shown in the form of a wiring diagram of another arrangement adapted for use in the practice of the present invention;

Figs. 7 and 8 are views, with parts in section, of two different embodiments which may be used successively for producing a log of a borehole;

Figs. 9 and 9–A are respectively side and front elevation views of modifications of elements shown in Figs. 1 and 7; and

Figs. 10 and 10–A are respectively side and front elevation views of a modification of elements shown in Fig. 8.

Turning now specifically to the drawing and first to Fig. 1, numeral 10 designates the wall of a borehole produced by the drilling operation, that is to say, by the cutting action of the drill bit and erosion of drilling fluid. The formations penetrated by the borehole are plastered with a mud sheath or filter cake of variable thickness and designated by numeral 11 in the drawing. Arranged in the borehole is a container or bomb 12 which is adapted for longitudinal movement along the bore of the well. If desired, the lower portion of container 12 may be a solid piece of metal or may be filled with a suitable quantity of a high density material 13, to add weight to container 12 and urge it downward through the borehole. Container 12 is suspended on a cable which, in practice, usually passes over a sheave at the surface of the earth and is then wound on a drum adapted to move the vessel vertically along the bore of the hole. The showing of hoisting equipment at the surface has been omitted from the drawing for the sake of clarity.

Mounted on container 12 is a first pair of arms

33, 34 and a second pair of arms 37 and 38. The lower ends of the arms are pivoted to ears 35 of container 12. The upper ends of the arms are provided with means such that the device is capable of being moved, either upwardly or downwardly, through the borehole without having the ends of the arms stuck in the formations.

The pair of arms 33, 34 is adapted to measure the true diameter of the borehole and, accordingly, has a configuration and is provided with a biasing means which will insure surfaces thereof penetrating through the mud sheath, and bearing against the faces of the subsurface formations. The portions of arms 33 and 34 adapted to penetrate through the mud sheath are designated as 39 and 40, respectively, and present a small surface to the mud sheath. Conveniently, portions 39 and 40 may be knife edge wheels or rollers about 1 or 2 inches in diameter pivotally mounted on the ends of arms 33 and 34. A pair of springs 36 is arranged to bias the upper ends of the pair of arms 33, 34 diametrically outward. It will be seen that one spring of the pair has one end secured in a well 12', or other suitable mounting means in the wall of container 12, and projects laterally with its other end resting against arm 33 while the other spring of the pair is similarly arranged to bias the free end of arm 34 diametrically outward. In the drawing the pair of springs 36 is represented as constructed of relatively heavy stock in order to indicate that they are capable of exerting a sufficient bias against end portions 39 and 40 to force them through the mud sheath as container 12 is moved along the bore of the hole.

The other pair of arms 37 and 38 are provided with ends 41 and 42 which have a relatively wide bearing surface and are adapted to rest against the exposed face of the mud cake without penetrating the cake. Preferably ends 41 and 42 should normally present a face having an area of at least about 16 square inches bearing against the mud sheath. A preferred form of ends 41 and 42 are shown, respectively, in side elevation and in side elevation partly in section in Fig. 8. The pair of arms 37 and 38 is provided with a pair of springs 36', each spring of the pair extending laterally from the well 12', or other suitable mounting means on the outer surface of container 12, to the spring arm it is adapted to bias. It will be seen that the springs 36' are shown as being constructed of lighter stock than the springs 36. It is to be emphasized that the bias exerted against the free ends 39 and 40 must be sufficient to cause them to penetrate through the mud sheath in a manner analogous to the penetration of a plow in surface soil while that exerted against free ends 41 and 42 is sufficient to insure continuous contact with the exposed surface of the mud cake without penetration of the mud cake. In practice it will be found satisfactory if springs 36 exert a force of about 200 pounds per square inch or more and springs 36' a force of not more than 5 pounds per square inch under compression.

In the embodiment shown, indicating systems are provided to indicate the magnitude of movements of the two pairs of arms. To this end, the cable designated by numeral 14, carries four insulated conductors designated by numerals 15, 16, 17, and 18. At the surface the conductors 15 and 16 are connected to battery 19 and recording galvanometer 20 and conductors 17 and 18 are connected to battery 21 and recording galvanometer 22. The recording galvanometers 20

and 22 are represented symbolically and are shown as producing a trace on a moving sensitized strip 23. The arrangement of strips of sensitized material for recording well logs is well known to the art and it will be understood that mechanism, not shown, will conventionally be provided for driving the strip in synchronism with the sheave over which the cable is trained so that the measurements recorded will be correlated with the depth of the container 12 in the borehole.

Within the container 12 is arranged a mounting 24 constructed of a suitable insulating material and having pivoted thereto two pairs of arms constructed of a suitable conducting material, one pair of arms is designated by numerals 25 and 26 and the second pair by numerals 27 and 28. Rheostats 29 and 30 are also mounted within the container and arranged so that the ends of arms 25 and 26 are in contact with rheostats 29 and 29', respectively, and the ends of arms 27 and 28 are in contact with rheostats 30 and 30', respectively. It will be seen that the circuit including battery 19 and recording galvanometer 20 at the surface of the earth is completed by means of conductors 15 and 16, arms 25 and 26, and rheostats 29 and 29', while the circuit including battery 21 and recording galvanometer 22 is completed through conductors 17 and 18, arms 27 and 28, and rheostats 30 to 30'.

Pivoted to each of the pointers 25, 26, 27, and 28 intermediate their ends are rods 31 which pass through the wall of container 12 through suitable packing glands 32. The rods 31 which are connected to the pair of arms 25 and 26 have their outer ends connected to arms 33 and 34, respectively.

As has heretofore been explained, arms 33 and 34 are provided with end portions 39 and 40 which present a small surface to the mud sheath and springs 36 which will bias the arms outwardly and cause the end portions 39 and 40 to cut through the mud sheath deposited on the wall of the hole whereby the end portions 39 and 40 come directly into contact with the faces of subsurface formations. On the other hand, arms 37 and 38 have the end portions 41 and 42 provided with relatively large areas and the springs 36' exert a relatively small bias so that the portions 41 and 42 simply ride on the exposed face of the mud sheath. Accordingly, the amount of resistance of rheostats 29, 29' included within the circuit of battery 19 and galvanometer 20 will be a function of the diameter of the hole produced by the cutting and erosion of the drilling operation while the amount of resistance of rheostats 30, 30' included within the circuit of battery 21 and the galvanometer 22 will be a function of the diameter of the exposed face of the mud cake. By the selection of suitable electrical constants in the circuits and the selection of galvanometers 20 and 22 having suitable responses, the traces produced on sensitized sheet 23 by galvanometers 20 and 22 will indicate the radius of the hole penetrating the subsurface formations and the radius of the exposed face of the mud cake, respectively, whereby the thickness of the mud cake in the borehole may be immediately obtained by determining the difference between the curves produced by galvanometers 20 and 22.

In Fig. 4 is shown a borehole traversing formations 44, 45, 46, and 47. Formations 45 and 47 are substantially impermeable and the amount

of filter cake deposited on the wall of the borehole adjacent these formations is very small. Formation 44 is quite porous or permeable and the filter cake built up against this formation is of substantial thickness. Formation 46 has a porosity and permeability substantially greater than that of formation 44 and the filter cake deposited against the wall of the borehole at this point is of substantially greater thickness than that adjacent formation 44. In the drawing of Fig. 4, the diameter of the bore within the mud cake is shown substantially uniform although such showing may not be typical of all bore holes. Opposite some porous formations the mud cake may build up so that the diameter of the hole through that formation is less than the average diameter through the other formations.

As the device of Figs. 1 and 2 is moved along the borehole shown in Fig. 4, the pair of arms 33 and 34 will move outwardly from container 12 at formation 44, inwardly at formation 45, outwardly at formation 46, and inwardly again at formation 47. The pair of arms 37 and 38 will move hardly at all as they pass formations 44, 45 to 46 and 47. As container 12 is moved along the bore of the hole, traces are produced on sensitized paper 23 at the surface of the earth, one trace indicating the changes in the resistance in the circuit in which the recording galvanometer 20 is arranged and the other trace indicating the changes in the resistance of the circuit in which galvanometer 22 is arranged.

The traces obtained by passing the device of Figs. 1, 2, and 3 through that portion of the borehole shown in Fig. 4 are shown in Fig. 5. Curve A is the trace produced by recording galvanometer 20 and indicates the lateral positions of the pair of arms 33, 34 and trace B is produced by galvanometer 22 and indicates the lateral positions of the pair of arms 37, 38. An increase in resistance in the circuit caused by outward movement of the pairs of arms is indicated in Fig. 5 by movement of a trace to the left, while a decrease in the resistance in the circuit caused by inward movement of the arms is indicated by movement of a trace to the right, the zero current or maximum resistance line of the curves being to the left of the chart. In Fig. 5 on trace A, the impermeable formations 45 and 47 are indicated by portions 50 and 51 and the permeable formations 44 and 46 by portions 52 and 53. On trace B the impermeable and the permeable formations do not appear.

It will be seen that where impermeable formations are penetrated and the thickness of the filter cake is negligible, the traces A and B are close together. In the more permeable portions of the borehole, the traces A and B are laterally separated by an amount directly proportional to the thickness of the mud sheath. The lateral distances separating portions 52 and 56 from curve B indicate respectively the thickness of the mud cake adjacent formation 44 and the thickness of the mud cake adjacent formation 46. It will be understood that if the device is suitably calibrated and division lines are placed on the sensitized paper 23 either before or as the log is being taken the thickness of the mud cake on the bore of the hole may be read off directly from the chart.

It will be understood that the practice of the present invention is not limited to any particular arrangement of apparatus. A modification of apparatus suitable for practicing the present in-

vention is shown in Fig. 6. In this apparatus many of the parts are identical with the embodiment of Figs. 1, 2, and 3 and in order to simplify the drawing many parts which duplicate those of the precedingly described figures are omitted, and the components of the electrical circuit shown symbolically. The device of Fig. 6 differs from that of Figs. 1, 2, and 3 in allowing the use of a cable having a single insulated conductor. In this embodiment the cable employed for lowering the container is designated by numeral. 60 and includes a single insulated conductor 61 and an outside metallic sheath 62. A recording galvanometer 63 and a source of alternating current 64 are arranged at the surface in a circuit including a condenser 65. The condenser, galvanometer and source of alternating current are connected to the insulated conductor by a connection 66 and to the metallic cable sheath which serves as a return conductor through connection 67. Also arranged at the surface is a source of direct current 68, a recording galvanometer 69 and a choke 70. Source of direct current 68, galvanometer 69 and choke 70 are connected to the insulated conductor 61 through conductor 71 and to the metallic sheath 62 through conductor 72. Arm 25 is connected to insulated conductor 61 of the cable by a conductor 73 including condenser 74 and arm 26 is connected to the metallic cable sheath through conductor 75. Arm 27 is connected to insulated conductor 61 through conductor 76 containing choke 77 and arm 28 is connected to metallic sheath 62 through conductor 78.

Condensers 65 and 74 serve to block out direct current from a portion of the circuit so that galvanometer 63 produces a trace which is a function of the amount of the resistance due to rheostats 29 and 29'. Similarly, chokes 70 and 77 serve to block out the alternating current from a portion of the circuit so that the trace produced by galvanometer 69 is a function of the amount of resistance due to rheostats 30 and 30'. By the selection of electrical units having suitable characteristics, the traces produced by galvanometers 63 and 69 may be directly compared and arranged to produce traces on a sensitized sheet resembling those produced on sensitized sheet 23 by the apparatus of Figs. 1, 2, and 3. It will be understood that if desired the depth of the instrument and galvanometer indications may be read by an operator at the surface of the earth and a chart plotted by hand rather than automatically recorded.

Another variation in the practice of the present invention is in the use of separate means for obtaining a log of the diameter of the borehole caused by the cutting of the drill bit and erosion of the drilling fluid and a separate log of the inside diameter of the exposed face of the mud filter cake deposited in the borehole. In Fig. 7 is shown an elevational view of an apparatus adapted to determine the true diameter of the borehole. In this figure container 12 is provided with a single pair of arms 33, 34. Arms 33 and 34 of this figure are provided with roller ends 39 and 40 and correspond to the numbers identified by the same numerals in the embodiment of Figs. 1 to 3. A pair of laterally extending springs 36 constructed of relatively heavy stock are arranged to bias the ends 39 and 40 outwardly so that the ends cut through the mud sheath and rest against the faces of the subsurface formations. Within the container is mounted rheostats 29, 29' and pivoted on a suitable mounting means 24 is a

pair of arms 25, 26 arranged to make contact with rheostats 29 and 29', respectively, and to be moved upon lateral movement of arms 33, 34. A cable 80 is arranged for lowering container 12 along the bore of the well and within the cable are insulated conductors 81 and 82 connected respectively to arms 25, 26. At the surface of the earth is arranged a recording galvanometer 20 and a source of direct current 19 electrically connected to insulated conductors 81 and 82 and adapted to produce a trace on a sensitized sheet which may be similar to sheet 25 of Fig. 1, but for the purpose of simplifying the drawing is not shown in Fig. 7. It will be seen that the device of Fig. 7 is adapted for producing a trace indicating the variations with depth of the true radius of the borehole, that is to say, the radius of the borehole on which the filter cake is deposited.

In Fig. 8 is shown a device adapted to determine the variations in diameter of the exposed face of the mud cake. In this embodiment, a container 12 is provided with the single pair of arms 37, 38. Arms 37, 38 are provided with ends 41 and 42 having a relatively large area and correspond to the arms identified by the same numerals in the embodiment of Figs. 1 to 3. Laterally exending springs 36' made of relatively small stock are arranged to bias the ends 41 and 42 outwardly so that they will remain in contact with the exposed face of mud sheath 11 but will not penetrate into the mud sheath. Within the container are rheostats 30, 30' and pivoted to mounting 24 within the container is a pair of arms 27, 28. A cable 83 is adapted for suspending the container and contains insulated conductors 84 and 85. The lower ends of conductors 84 and 85 are connected to arms 27 and 28, respectively, while the upper ends are connected at the surface of the earth to a source of direct current 21 and a recording galvanometer 22. It will be seen that the embodiment of Fig. 8 is adapted to take a log of a well showing the variations with depth in radius of the face of the mud cake.

The thickness of a mud cake in a well may be determined by using first one of the devices of Figs. 7 or 8 to take a log of the well and then one of the other of said devices. That is to say, the device of Fig. 7 may first be run in the well to determine the true radius of the borehole and the device of Fig. 8 then run into the borehole to determine the variations in radius of the exposed face of the filter cake. From the information obtained from the two runs, a log may be plotted showing the variations with the depth of the thickness of the filter cake. If desired, the device of Fig. 8 may first be run in the hole to determine the variations in radius of the exposed face of the filter cake and the device of Fig. 7 then used to determine the true radius of the borehole and a log showing the variations in the thickness of the filter cake with the depth of the borehole plotted as before described.

In Fig. 9 there is shown a side elevation view of a runner 54 which may be used in place of the wheel elements 39 and 40 attached, respectively, to arms 33 and 34 illustrated in Figs. 1 and 7. This runner 54 is curved so that it will readily pass over projections in the wall of the borehole. Runner 54 also is knife edged as indicated in the front elevation view of Fig. 9–A so that it will readily cut through the mud sheath and bear against the formation surface of the borehole.

In Figs. 10 and 10–A, respectively, side elevation and front views are shown of modifications of ends which are adapted to replace the elements

41 and 42 in Fig. 8. The elements 55 shown in Figs. 10 and 10–A may be made a part of arms 37 and 38. The end 55 of arm 37 is constructed sufficiently broad to provide a surface which will bear against, without penetrating, the mud sheath in the borehole. Likewise, the end 55 is preferably curved as illustrated in Fig. 10 so that when the container 12 is passed longitudinally through the borehole the ends of the arms will readily pass over irregularities in the surface of the mud sheath and will cause the arms to move inwardly or outwardly in accordance with the variations in the surface of the mud sheath.

Although we have described several modifications of our invention wherein at least a pair of arms on diametrically opposite sides of the container 12 are arranged to operate a pair of variable resistors, it will be understood that additional pairs of arms, operatively connected to indicating means, may be spaced diametrically opposite each other around the circumference of the container. Also, if desired, only one of the arms in any diametrical pair may be used to operate a variable resistor and associated indicator.

While we have shown and described various devices adapted for use in the practice of the present invention, it will be understood that still other devices may be employed. For example, the well logging device disclosed by Kinley in U. S. Patent 2,102,080, December 14, 1937, and by Kinley et al., U. S. Patent 2,267,110, December 23, 1941, may be employed in the practice of the present invention by modifying said devices so that a log is obtained indicating the variations with the depth of the borehole of the radius of the exposed face of the mud cake and variations of the radius of the borehole produced through the formations by the cutting of the drill bit and erosion of the drilling fluid. It will be apparent to a workman skilled in the art that other devices may also be adapted for the practice of the present invention.

Having fully described the practice of the present invention, what we desire to claim is:

An apparatus for determining the thickness of a mud sheath deposited on a portion of the wall of a borehole penetrating subsurface formations, comprising a body adapted to be lowered into the borehole, a first pair of spaced arms pivotally mounted on said body and presenting a knife edge capable of penetrating the mud sheath, biasing means arranged to bias the arms outwardly to force said arms through the mud sheath and into contact with the faces of the formations penetrated by the borehole, a second pair of spaced arms pivotally mounted on said body and presenting a surface area incapable of penetrating the mud sheath, biasing means arranged to bias outwardly the said second pair of arms and maintain them in contact with the exposed face of the mud sheath, a first indicating system operatively connected with the first pair of arms for producing an indication which is a function of the lateral extension of the first pair of arms and hence the true diameter of the borehole and a second indicating system operatively connected with the second pair of arms for producing an indication which is a function of the lateral extension of the second pair of arms and hence the apparent diameter of the borehole.

THEODORE A. HUBER.
GEORGE E. CANNON.

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