

X 1041 C

Sept. 4, 1962

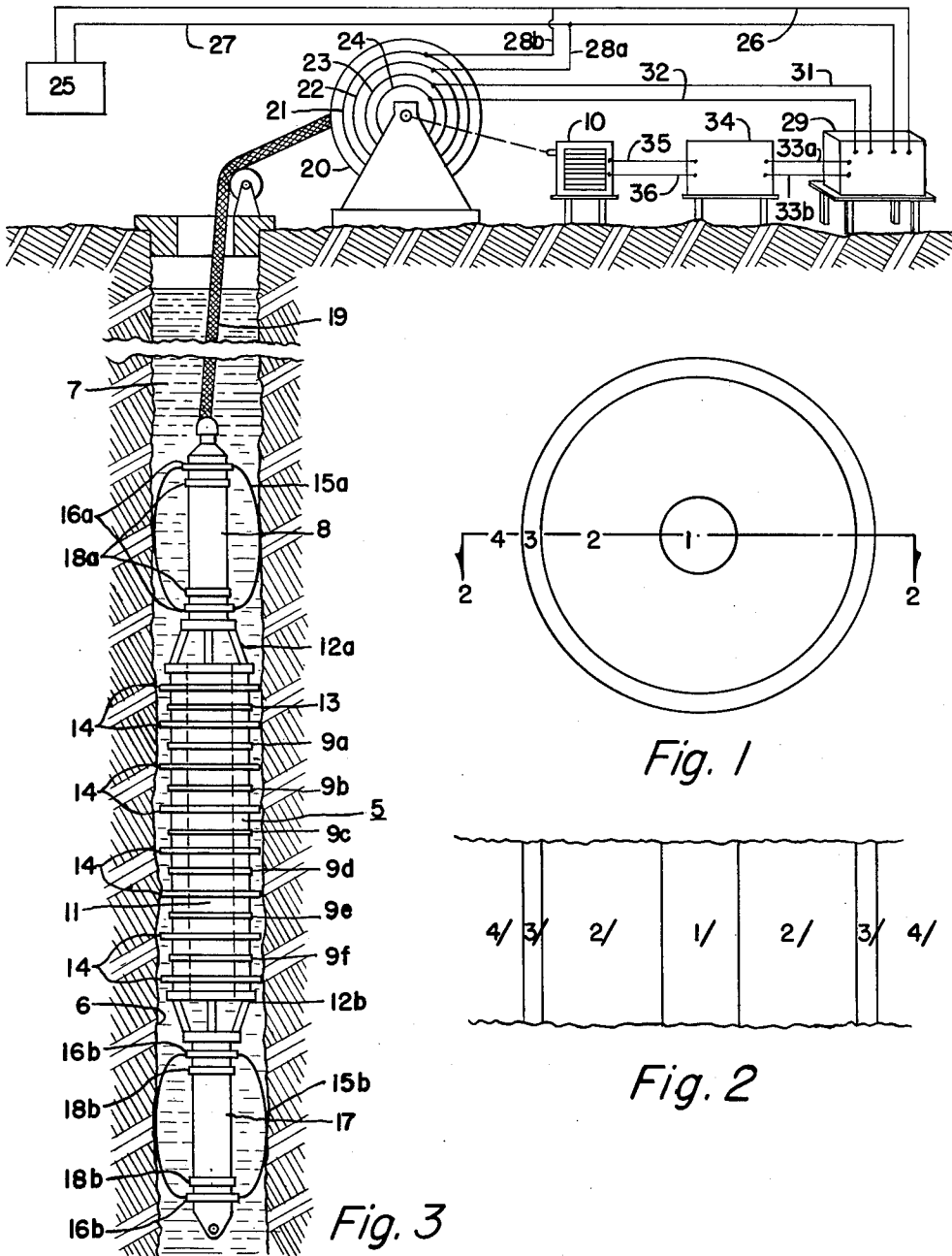
H. F. DUNLAP ETAL

3,052,835

ELECTRICAL WELL LOGGING INSTRUMENT

Filed March 25, 1954

3 Sheets-Sheet 1



ATTEST

Lloyd A. Heneveld

INVENTORS

Henry F. Dunlap

BY Leonidas P. Whorton

Herbert E. Birch

Attorney

Sept. 4, 1962

H. F. DUNLAP ETAL

3,052,835

ELECTRICAL WELL LOGGING INSTRUMENT

Filed March 25, 1954

3 Sheets-Sheet 2

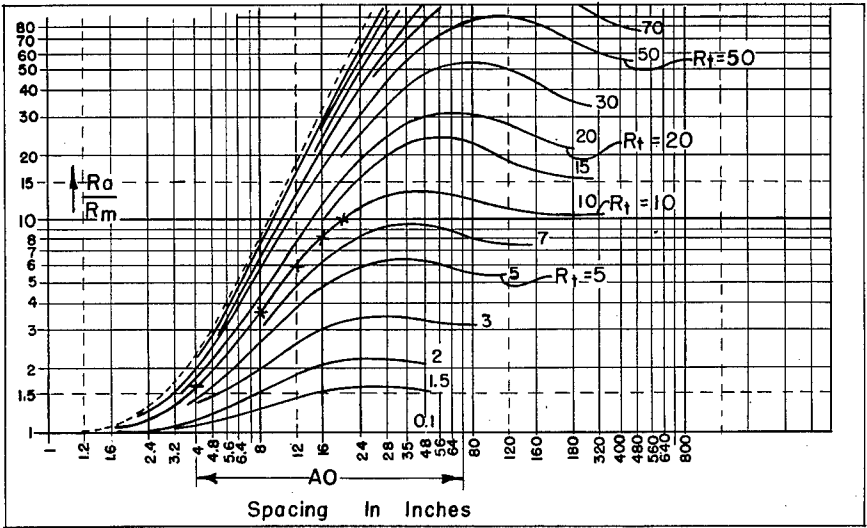


Fig. 4

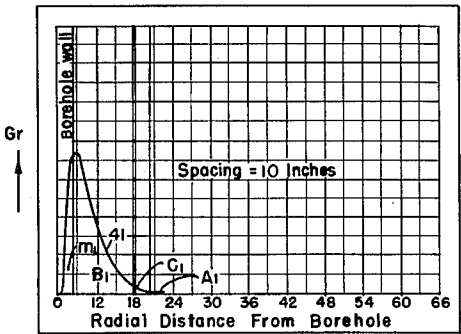


Fig. 8

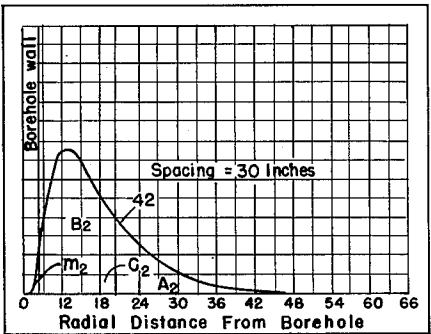


Fig. 9

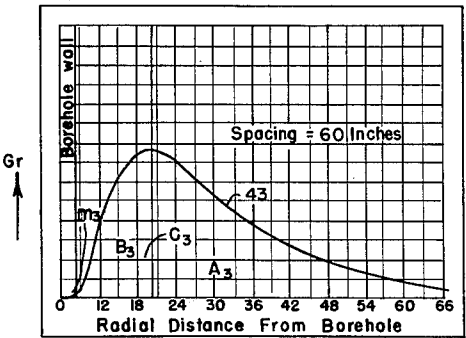


Fig. 10

ATTEST

Lloyd A. Heneveld

INVENTORS

Henry F. Dunlap

Leonidas P. Whorton

BY

Robert E. Birch
Attorney

Sept. 4, 1962

H. F. DUNLAP ETAL

3,052,835

ELECTRICAL WELL LOGGING INSTRUMENT

Filed March 25, 1954

3 Sheets-Sheet 3

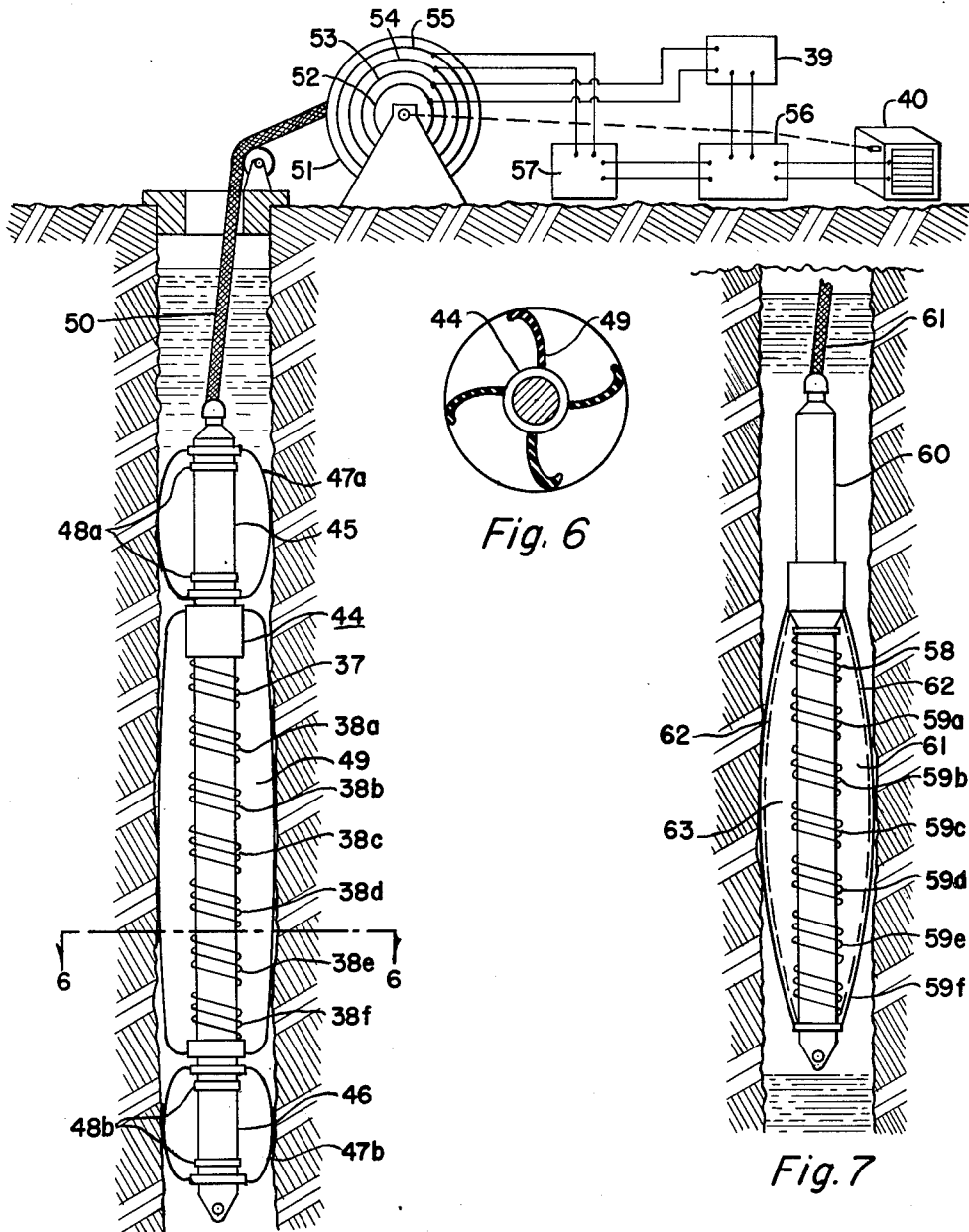


Fig. 5

Fig. 7

ATTEST

Lloyd A. Heneveld

INVENTORS

Henry F. Dunlap

BY Leonidas P. Whorton

Harbert E. Birch
Attorney

1

3,052,835

ELECTRICAL WELL LOGGING INSTRUMENT

Henry F. Dunlap and Leonidas P. Whorton, Dallas, Tex.,
assignors to The Atlantic Refining Company, Philadelphia, Pa., a corporation of Pennsylvania

Filed Mar. 25, 1954, Ser. No. 418,588

14 Claims. (Cl. 324-1)

This invention relates to apparatus for electrically logging of boreholes and more particularly this apparatus is adapted for examining subterranean formations of the existence therein of displaceable hydrocarbons.

An ever present problem which faces the oil industry in the drilling of wells is the danger of drilling through formations which contain displaceable hydrocarbons without being aware of that fact. Much work has been done toward providing apparatus and methods for detecting the existence of oil in formations in order to decrease the probability of passing up profitable oil- or gas-bearing formations.

While numerous methods and apparatus have been developed which have been useful in determining whether oil or gas exists in specific formations, there has not yet been developed a well bore logging method or apparatus which will detect the presence of displaceable hydrocarbons in a formation. The present invention relates to a well logging instrument which can be used to detect the presence of displaceable hydrocarbons in a formation. We have discovered as set forth in our co-pending application, Serial No. 317,102, filed October 27, 1952, by Ellis W. Shuler, Jr., Henry F. Dunlap, and Lloyd E. Gourley, Jr., entitled "Method and Apparatus for Locating Displaceable Oil in Subterranean Formations," and now Patent No. 2,782,364, that in drilling with a drilling fluid having a resistivity greater than connate water, that if displaceable hydrocarbons are present in a formation the drilling fluid will displace both the displaceable hydrocarbons and nearly all the connate water in the invaded region. However, since the connate water cannot flow in the invaded region of the virgin formation, a bank of connate water is built up at a radial distance from the borehole between the virgin formation and the invaded zone. If displaceable hydrocarbons are not present in a formation this bank of connate water will not be built up by the drilling fluid. This application is a continuation-in-part of the above mentioned co-pending application, Serial No. 317,102, and specifically discloses well logging instruments to be used in locating displaceable oil.

An object of this invention is to provide a well logging instrument which is capable of detecting the bank of connate water which is formed when a formation containing displaceable hydrocarbons is traversed by drilling with the aid of drilling fluid having a resistivity higher than connate water.

Another object of this invention is to provide a well logging instrument which is capable of measuring the apparent electrical resistivity of a plurality of radially contiguous increments of formations penetrated by a borehole whereby to determine whether or not the bank of connate water exists in the formation.

A still further object of this invention is to provide a well logging instrument which has means for impeding the flow of current within the borehole which contains conductive drilling fluid, thus providing means for eliminating the effect of such current on the sensitivity of the receiving elements in measuring the apparent resistivities of a plurality of short radially contiguous increments of the formation which is penetrated by the borehole.

Other objects and advantages of the present invention

2

will become apparent from the detailed explanation and accompanying drawings.

FIGURE 1 diagrammatically shows the bank of connate water which is displaced by the drilling fluid.

5 FIGURE 2 shows a cross-section of FIGURE 1.

FIGURE 3 is a diagrammatic representation of a borehole instrument, particularly showing the instrument which has a plurality of disk-like elements which impede the flow of the current in the borehole.

10 FIGURE 4 shows departure curves which indicate the apparent resistivities which have been calculated will be picked up by the current electrodes for various spacings between the current and potential electrodes.

15 FIGURE 5 shows a modified instrument which has incorporated therein induction coils and fins for impeding the flow of the current in the borehole.

FIGURE 6 shows a cross-section of the instrument of FIGURE 5.

20 FIGURE 7 shows a modification of the instrument shown in FIGURES 5 and 6; and

FIGURES 8, 9, and 10 show graphs that indicate the relative contributions which various radial sections of the formation contribute to the signal picked up for various spacings of the coils of FIGURE 5 or 7.

25 The apparatus of this invention was invented to detect a zone of low resistivity which is formed by connate water displaced by drilling fluid when a formation containing displaceable hydrocarbons is traversed. Heretofore electrical well logging instruments have been used to measure the resistivity of a formation, however, in almost all cases the receiving elements have been spaced a great distance from the transmitting element where the current in the borehole is not too great. Consequently, there has been very little concern about the current in the borehole affecting the signal picked up by the pickup elements. In those cases where the pickup elements have been located at a short distance from the transmitting element departure curves have been used so that the apparent resistivities recorded could be corrected for the effect of the mud current. However, such corrections are still subject to a great degree of error.

30 In the present invention the instrument has pickup elements spaced so close to the transmitting element that the current in the borehole is very substantial in the vicinity of such pickup elements. Consequently, the current flowing in the borehole fluid masks the effects on the pickup elements caused by the current flowing through the formation adjacent the borehole. This masking caused by the current in the borehole fluid cannot be taken into account and corrected by departure curves accurately enough to permit detection of the "low zone" referred to above. The purpose of this invention is to prevent the flow of current in the borehole so that the effect on the pickup elements caused by the current flowing in the formation adjacent the borehole is not masked and the resistivities of several radial increments of the formation close to the borehole can be accurately recorded so that the presence of the "low zone" is indicated on a recording chart.

35 This invention may best be understood by referring to the drawings. In FIGURE 1 is shown the three zones which are formed when a formation containing displaceable hydrocarbons is traversed by means of a rotary drilling apparatus using drilling fluid having a resistivity greater than connate water. When a borehole is drilled through a porous formation using a weighted drilling fluid or mud, as is customary in the rotary method of drilling, filtrate from the drilling fluid invades the formation in the vicinity of the borehole thereby displacing back into the formation a portion of the indigenous formation fluid. In FIGURE 1 zone 2 of the formation 2-3-4 represents the zone of the formation immediate-

ly adjacent the borehole 1 from which the original fluids have been substantially displaced by the invading filtrate.

We have discovered that when displaceable hydrocarbons are present in a formation that the displaceable hydrocarbons back in the formation were pushed radially away from the borehole but the formation water, commonly referred to as "connate water," built up a bank immediately in advance of the invading front. Under such conditions, therefore, the zone 2 became substantially filled with a high resistivity mud filtrate, zone 3 became substantially filled with the relatively low resistivity formation water, while the fluid of zone 4 remains substantially identical to the fluid as it existed in the virgin formation; that is, zone 4 remained filled with oil accompanied by irreducible formation water. Therefore a measure of the specific resistivity of the formation 2—3—4 as a function of distance from the borehole would show the specific resistivity of zone 2 to be relatively high, the specific resistivity of zone 3 to be relatively low, and the specific resistivity of zone 4 to be relatively higher than that of zone 3.

We have also discovered that the radial bank of connate water is a relatively thin bank which very often exists close to the borehole. In fact, we have estimated that the bank exists at shallow depths of invasion from 4 to 20 inches radially from the borehole. This bank of connate water, hereinafter referred to as the "low zone," may be very thin, being in one case about four (4) inches wide at 16 inches from the face of the hole. Therefore, it has become necessary to have various spacings at close intervals for investigating close to the borehole in order to detect the low zone. In using a conventional well logging instrument with very short spacings between the transmitting element and receiving element we were not able to detect the low zone since the effect of the current in the formation upon the receiving elements was masked by the effect of the current flowing in the borehole fluid.

The effect of this masking, referred to above, will be evident as applied to an electrical logging system using electrodes if the path of the current from the current electrode in the borehole is considered. Referring to FIGURE 3, wherein is shown the apparatus of this invention, there is disclosed a current electrode 13 from which current flows radially. Naturally, if the entire area surrounding the current electrode was homogeneous the current would flow in all directions with the same intensity; but in this case where a borehole 6 is filled with drilling fluid of low resistivity much more current flows in the borehole fluid, especially near the current electrode. Eventually at a greater distance from the current electrode the current passes into the formation and the current is attenuated and the flow in the borehole is not as great. The masking effect produced by this current flow in the drilling fluid near the current electrode can best be illustrated by referring to FIGURE 4.

FIGURE 4 shows at different spacings calculated apparent resistivities of a formation which would be picked up by potential electrodes spaced at various distances from a current electrode. This theoretical curve does not take into account the invasion of the mud into the formation but it does illustrate that at very close spacings from the current electrode the current in the mud does appreciably affect the readings of the apparent resistivities picked up by the potential electrodes. In FIGURE 4 it is assumed that the diameter of the drill hole is eight inches and:

R_a = Apparent resistivity

R_m = Mud resistivity

R_t = True resistivity of the formation

A_o = Spacing of the lateral potential electrodes from the current electrode.

R_a , R_m , R_t are expressed in ohm-meters, and A_o expressed in inches. Taking the example where $R_t=10$ ohm-meters and assuming for purposes of illustration

$R_m=1$ ohm-meter, it is seen that the R_a recorded by the potential electrode spaced four inches from the current electrode is only 1.7 ohm-meters and at eight inches R_a is 3.7 ohm-meters, etc. Finally at 20 inches and greater spacings the R_a would be approximately 10 ohm-meters. It can readily be appreciated that one could never be certain what the true resistivities of the formation which are measured by potential electrodes spaced less than 20 inches from the current electrode are: therefore, it is evident that some means should be provided whereby the R_a 's measured by the potential electrodes spaced less than 20 inches from the current electrodes are more approximately equal to R_t . This is particularly true if the "low zone" referred to above is to be detected.

In FIGURE 3 is shown an apparatus which is capable of substantially eliminating the effects of current in the borehole fluid and thereby is capable of detecting the low zone created by the bank of connate water. In this figure, sonde 5 is shown located in borehole 6 which is filled with an electrically conductive fluid 7. Sonde 5 consists of an upper housing 8 containing switching means or means for telemetering the potentials picked up by the potential electrodes. If switching means is provided in housing 8 the signals from receiving elements 9a, 9b, 9c, 9d, 9e, and 9f are sequentially recorded on recorder 10. However, if telemetering means is provided in the housing 8 the signals from the receiving elements may be almost simultaneously recorded on the recorder 10. Sonde 5 also consists of a hollow intermediate section 11 connected to housing 8 by means of coupling 12a, and a lower section 17 connected to section 11 by means of coupling 12b. Couplings 12a and 12b have openings therein which allow the mud to pass through the section 11 when the well instrument is being lowered or raised. Housing 8 and section 17 may be made of any desirable material although a non-corrosive material, such as stainless steel, is to be preferred. Intermediate section 11 is made of non-conducting material, such as Bakelite.

A current electrode 13 which preferably comprises a band of non-corrosive metal, such as stainless steel, is secured to section 11 near the top thereof. The plurality of electrodes 9a, 9b, 9c, 9d, 9e, and 9f comprising bands of non-corrosive metal are secured to the section 11 at substantially equally spaced intervals below current electrode 13. As stated above, these electrodes are spaced very close together and close to the current electrode in order to be able to detect the low zone created by the displaced connate water. These electrodes should be less than nine inches apart and the first electrode 9a should be spaced less than 12 inches from the current electrode 13. In the instrument illustrated both of these spacings are four inches. It is necessary that a plurality of such electrodes be used. In the FIGURE 3 there are shown six electrodes but in practice probably eleven or twelve, or even more, are preferable.

As stated above, difficulty arises in measuring the true resistivities with the electrodes which are spaced close to the current electrode 13, because the current in the borehole masks the effect which the current flowing in the formation adjacent the borehole has on the electrodes. In this embodiment of the invention a plurality of rings 14 are provided between each of the electrodes. These rings 14, which are made of a non-conductive material which is flexible, such as rubber, impede the flow of the current in the borehole and therefore eliminate the effect of the current in the borehole on each of the electrodes. Rings 14 are normally of a diameter less than the diameter of the borehole in order to eliminate any jamming of the rings against the wall of the borehole which might cause the instrument to become stuck in the borehole. Also too much flexing of rings 14 would give a distorted record because such flexing might change the effective spacing of the potential electrodes and thus change the

5

potential which the potential electrode would normally pick up.

Mounted on each end of the instrument are centralizers 15a and 15b. These centralizers each have a pair of collars 16a and 16b which are slidably mounted on housing 8 and lower section 17, respectively. Located between each of the slidable collars are rigid collars 18a and 18b which limit the sliding movement of collars 16a and 16b. These centralizers are provided to center the instrument in the center of the borehole so that the rings 14 are centered to give the maximum blocking effect against the flow of current in the borehole.

Also shown in FIGURE 3 is the transmitting and recording mechanism which is used to record the signals picked up by each of the potential electrodes. Potential electrodes 9a, 9b, 9c, 9d, 9e, and 9f are electrically connected (not shown) to the switching mechanism or telemetering means which is located in housing 8. The signal is transmitted from electrodes 9a-9f through the cable 19 to the surface of the earth. The cable 19 is wound on reel 20 which is adapted to be rotated by a power source, not shown, to lower and raise sonde 5 through the borehole. Reel 20 is provided with a plurality of slip rings 21, 22, 23, and 24 to which the recording mechanism and a source of power is connected. The source of power 25 is connected through conductors 26 and 27 and conductors 28a and 28b to slip rings 21 and 22 to provide a source of power for the current electrode 13 and switching mechanism or telemetering means which is located in housing 8. Source of power 25 also provides power for potentiometer 29 which is electrically connected to conductors (not shown) in cable 19 by means of conductors 31 and 32 and slip rings 23 and 24, thus providing means for conducting the signal which is sent from housing 8 to potentiometer 29. Potentiometer 29 is connected through conductors 33a and 33b to rectifier 34 and after the signals are rectified they are passed through wires 35 and 36 to recorder 10. It will be appreciated therefore that the signals which are sent from housing 8 are transmitted to slip rings 23 and 24 through conductors 31 and 32 to potentiometer 29 through conductors 33a and 33b to rectifier 34, and through conductors 35 and 36 to recorder 10. Any other well known arrangement of potentiometers, rectifiers, or recorders can be used without departing from the scope of this invention. It should be understood that the above description is merely for purposes of illustration only.

In FIGURE 5 is shown a well logging instrument which is used in an induction logging system. This induction logging system comprises a coil 37 through which alternating current of appropriate frequency is made to flow. This coil is commonly referred to as a "transmitter." The alternating magnetic field thus created by the current generates eddy currents which currents follow circular paths, coaxial with the hole and the coil system, in the formation surrounding said hole. These eddy currents create a secondary magnetic field which induces an electromotive force in receiving coils 38a, 38b, 38c, 38d, 38e, and 38f, which are commonly referred to as "receivers." The energy received by the coils 38a, 38b, etc. is affected by the conductivities of the formation surrounding the borehole. This energy in each of the coils is transmitted either sequentially or simultaneously to the amplifier 39 and recorded on the recorder 40. The record recorded indicates the apparent resistivities of radial increments of the formation.

The greatest problem encountered in obtaining a record which will show the low resistivity zone created by the bank of connate water, is the masking effect which the current flowing in the borehole has upon the energy received in each of the receiving coils. This masking effect is particularly troublesome upon the receiving coils which are located near the transmitting coil.

As stated above the conductivities of a section of the ground surrounding the borehole affect the energy re-

6

ceived by each of the coils. This effect which a section of a formation has upon the energy received by the receiving coil is dependent upon the location and dimension of the section. In fact, the part of the formation contributing the major portion of the signal in phase with the transmitter is that part of the formation which is located approximately at a radial distance from the borehole equal to one-half the distance between the transmitter and the receiver coil. For example, a radial section of a formation located at a radial distance of 2½ feet from the borehole has the most effect upon a receiving coil spaced five feet from the transmitting coil, while the energy received by a receiving coil spaced ten inches from the transmitting coil is affected the most by a radial section of the formation located five inches from the borehole. This can be illustrated by a well known formula $E=KC_A G_A$ where:

E =Signal picked up by receiving coil.

G_A =Geometrical factor which depends exclusively upon the geometry and location of a radial section A of a formation in relation to the transmitting and receiving coils.

C_A =Conductivity of section A.

The induction log conventionally recorded actually represents the value of E/K which by definition is called the apparent conductivity Ca . The value of Ca for a radial section of ground A can then be written:

$$Ca=C_A G_A$$

and the value of Ca for radial sections of ground (A, B, C) having different conductivities can be written:

$$Ca=C_A G_A+C_B G_B+C_C G_C+\dots$$

It is therefore evident that the apparent conductivity measured by each receiving coil is dependent upon the geometrical factor and conductivity of each different section of the ground.

This phenomenon can be best understood by referring to FIGURES 8, 9, and 10 which graphically show the effect of the various radial sections of the ground upon the energy received by receiving coils spaced at 10, 30 and 60 inches, respectively.

In FIGURES 8, 9, and 10, the curves 41, 42, and 43, respectively, represent the "radial investigation characteristic" G_r of various radial increments spaced radially from the well logging instrument for each of three transmitting and receiving coil spacings. The geometrical factor of each radial increment spaced from the well instrument is equal to the ratio of the area under the curve representing each radial increment to the total area under the curve. For example, the geometrical factor for the mud (G_m) in FIGURE 8 is the ratio of the area represented by m_1 to the total area $m_1+A_1+B_1+C_1$ or

$$G_m=\frac{m_1}{m_1+A_1+B_1+C_1}$$

It is evident from the areas m_1 , m_2 , and m_3 that the geometrical factor for the mud when the receiving coil is spaced 10 inches from the transmitting coil is very much greater than when the receiving coil is spaced 30 or 60 inches from the transmitting coil and therefore the geometrical factor for the mud gets progressively smaller as the spacing of the receiving coil is increased.

The total apparent conductivity Ca which would be picked up by the coils according to FIGURES 8, 9, and 10 would be equal to:

$$Ca=G_m C_m+G_A C_A+G_B C_B+G_C C_C$$

where

$$G_A=\frac{A}{m+A+B+C}; G_B=\frac{B}{m+A+B+C}$$

and

$$G_C=\frac{C}{m+A+B+C}$$

and C_m , C_A , C_B , and C_C are the conductivities of the various sections. It is a well known fact that the conductivity of the mud C_m is usually much greater than conductivities of the sections of the formation surrounding the borehole (C_A , C_B , C_C), and therefore the contribution of the mud ($G_m C_m$) to the total C_a picked up by the receiving coil in many cases constitutes a considerable part of the total C_a measured by the receiving coil, especially when the geometrical factor G_m is large as shown in FIGURE 8. Therefore, the effect of the mud upon the total apparent conductivity in many cases will mask the effect which the formation and invaded zone have upon the total apparent conductivity. Consequently, if the approximate true conductivity of the formation and invaded zone surrounding the borehole is desired to be picked up by the receiving coil the geometrical factor of the mud G_m should be decreased or the conductivity of the mud should be decreased so that $G_m C_m$ is considerably decreased.

It has been found that the geometrical factor of the mud can be decreased by a system of coils which is commonly referred to as a focusing system. This system appreciably decreases the masking effect caused by the mud in cases where the receiving coil is spaced quite a distance from the transmitting coil; however, in the cases where the receiving coil is spaced very close to the transmitting coil the system of focusing does not appreciably help. Therefore, we have found that the conductivity of the mud has to be decreased in order to eliminate the masking effect caused by the mud.

FIGURES 5 and 6 show instruments each of which has means for decreasing the conductivity of the mud or in other words in decreasing the flow of current in the mud.

FIGURE 5 shows a sonde 44 on which a plurality of receiving coils 38a, 38b, 38c, 38d, 38e, and 38f are mounted. Above the receiving coil is transmitting coil 37. Sonde 44 comprises an upper portion comprising a housing 45 in which the switching mechanism or telemetering mechanism is mounted and a lower portion 46 extending from the sonde. Housing 45 and lower portion 46 have mounted thereon centralizers 47a and 47b, respectively. These centralizers are similar to centralizers 15a and 15b as shown in FIGURE 3 and also have cooperating collars 48a and 48b which limit the movements of the centralizers. Sonde 44 also has mounted thereon vertical fins 49 which are made of flexible material such as rubber. Fins 49 substantially prevent the flow of current within the borehole since the current tends to flow in a circular path radially around sonde 44. In other words, the fins 49 greatly decrease the conductivity of the mud in the borehole and consequently the contribution which the mud has to the apparent conductivity measured by each receiving coil is decreased to a minimum. Thus this invention provides means for accurately measuring the conductivities of a formation close to a borehole which was drilled with a drilling fluid without such measurement being detrimentally influenced by the mud in the borehole. This invention especially provides means for accurately measuring the apparent conductivities of the zone in the formation invaded by the drilling fluid and a bank of connate water located immediately adjacent and outwardly from said invaded zone.

FIGURE 5 briefly illustrates apparatus suitable for use with our induction well logging instrument in order that the signals picked up by the receiving coils can be transmitted to the surface of the ground and then recorded. Such apparatus comprises cable 50 which is connected to sonde 44 and wound on reel 51 which is adapted to be rotated by a power source, not shown, to raise and lower sonde 44 through the borehole. Reel 51, like reel 20 of FIGURE 1, is provided with a plurality of slip rings 52, 53, 54, and 55. Slip rings 52 and 53 are electrically connected to receiving coils 38a, 38b, 38c, 38d, 38e, and 38f through conductors, not shown, in cable 50. The signal from the receiving coil is there-

fore transmitted to slip rings 52 and 53 to amplifier 39 and thence to recorder 40. A phase sensitive detector 56 which is controlled by transmitting oscillator 57 is connected between amplifier 39 and recorder 40 so that only that part of the received signal that is in phase with the current in the transmitter coil 37 is recorded. Oscillator 57 sends an A.C. signal to transmitter coil 37 by means of slip rings 54 and 55 and conductors, not shown, within the cable 50.

Another modified induction well logging instrument is shown in FIGURE 7. This well logging instrument is almost identical to that shown in FIGURE 5 in that it has a transmitter 58, receiving coils 59a, 59b, 59c, etc., housing 60, and cable 61 all of which function in the manner referred to above. The main difference between the instrument shown in FIGURE 5 and the instrument shown in FIGURE 7 is the means for centralizing the sonde. FIGURE 7 has a plurality of ribs 62 which extend vertically from the upper end to the lower end of the sonde. Ribs 62 are of the leaf spring type and are so constructed that they extend in an arc radially from the sonde toward the wall of the borehole. Extending radially from the body of the tool to each of the ribs 62 are insulating sheets 63 made of rubber or other insulating material. Since currents circulate about the tool circumferentially in induction logging, these sheets 63 block the flow of the current in the mud in the borehole or, in other words, decrease the conductivity. Thus, it is seen that the instrument shown in FIGURE 7 also provides means for eliminating the effect which the mud has on the apparent conductivity measured by the receiving coils of an induction logging tool.

It is evident from the above disclosure that the various instruments of this invention are adapted to measure and record the apparent resistivities of a formation close to a borehole which was drilled with a drilling fluid without being detrimentally affected by the current flowing in the borehole. It is also evident that the various instruments disclosed herein are capable of detecting the presence of a bank of connate water located radially from the borehole, whereas presently used logging tools were not capable of detecting this bank of connate water because of the masking effect which the current flowing in the borehole has upon the signal picked up by the receiver elements.

While the above describes and shows the preferred embodiments to be used in our invention, the above description of the various instruments is explanatory thereof and only and various changes in size, shape, materials and arrangements may be made without departing from the scope of this invention. For example, the use of a plurality of current electrodes and one potential electrode as permissible by the reciprocity theorem would fall within the scope of this invention. Specifically, it should be understood that this invention shall not be limited to the measuring of formation resistivities with the use of either induction methods or electrode methods such as normals, laterals, or differential laterals, and that well instruments made according to this invention can be employed in any of these methods. Further, it should be understood that this invention shall only be limited as defined in the appended claims.

What is claimed is:

1. Apparatus for logging earth formations surrounding a well bore containing a conductive fluid comprising an elongated non-conductive support member adapted to slide in said well bore, transmitting means on said support member adapted to establish an electrical field in said fluid and said earth formations, at least three receiving means on said support member adapted to receive electrical energy transmitted through an equivalent number of different vertically disposed portions of said earth formations, said receiving means all being of like character and at least one of said receiving means being located adjacent said transmitting means at a distance such

that electrical energy transmitted through said fluid essentially masks the electrical energy transmitted through said earth formations, and means on said support member adapted to impede the transmission of electrical energy through said fluid.

2. Apparatus in accordance with claim 1 wherein at least one of the said receiving means is located less than twelve inches from the transmitting means.

3. Apparatus for logging earth formations surrounding a well bore containing a conductive fluid comprising an elongated non-conductive support member adapted to slide in said well bore, at least one transmitting electrode means on said support member adapted to establish an electrical field in said fluid and said earth formations, at least three receiving electrode means on said support member adapted to receive electrical energy transmitted through an equivalent number of different vertically disposed portions of said earth formations, said receiving electrode means all being of like character and at least one of said receiving electrode means being located adjacent said transmitting electrode means at a distance such that electrical energy transmitted through said fluid essentially masks the energy transmitted through said earth formations, and means on said support member adapted to impede the transmission of electrical energy through said fluid.

4. Apparatus in accordance with claim 3 wherein at least one of the receiving electrode means is located less than twelve inches from the transmitting electrode means.

5. Apparatus in accordance with claim 3 wherein the means adapted to impede the transmission of electrical energy through the conductive fluid comprises at least one flat ring of non-conducting material disposed between the transmitting electrode means and the receiving electrode means, said ring being secured to the supporting member at the circumference of the inner diameter and having an outside diameter substantially equal to the diameter of the well bore.

6. Apparatus for logging earth formations surrounding a well bore containing a conductive fluid comprising an elongated non-conductive support member adapted to slide in said well bore, at least one current electrode on said support member adapted to establish an electrical field in said fluid and said earth formations, at least three potential electrodes vertically displaced from one another and from said current electrode on said supporting member and adapted to measure potential difference between each of said potential electrodes and a reference potential electrode at the surface of the earth, at least one of said potential electrodes being located adjacent said current electrode at a distance such that electrical energy transmitted through said fluid essentially masks the energy transmitted through said earth formation, and means on said support member adapted to impede the transmission of electrical energy through said fluid.

7. Apparatus in accordance with claim 6 wherein at least one of said potential electrodes is located less than twelve inches from said current electrode.

8. Apparatus in accordance with claim 6 wherein the means adapted to impede the transmission of electrical energy through said fluid comprises at least one flat ring of nonconducting material disposed between the current electrode and the potential electrodes, said ring being secured to the supporting member at the circumference of the inner diameter and having an outside diameter substantially equal to the diameter of the borehole.

9. Apparatus for logging earth formations surrounding a well bore containing conductive fluid comprising an elongated non-conductive support member adapted to slide in said well bore, at least one current electrode on said support member adapted to establish an electrical

field in said fluid and said earth formations, at least three pairs of potential electrodes vertically displaced from each other and from said current electrode on said support member adapted to measure the potential difference between each individual pair of potential electrodes, at least one of said pairs of potential electrodes being located adjacent said current electrode at a distance such that electrical energy transmitted through said fluid essentially masks the energy transmitted through said earth formations and means on said support member adapted to impede the transmission of electrical energy through said fluid.

10. Apparatus in accordance with claim 9 wherein at least one pair of the potential electrodes is located less than twelve inches from the current electrode.

11. Apparatus in accordance with claim 9 wherein the means adapted to impede the transmission of electrical energy through the fluid comprises at least one flat ring of non-conducting material disposed between the current electrode and the potential electrodes, said ring being secured to the support member at the circumference of the inner diameter and having an outside diameter substantially equal to the diameter of the well bore.

12. Apparatus for logging earth formations surrounding a well bore containing a conductive fluid comprising an elongated non-conductive support member adapted to slide in said well bore, transmitting means on said support member adapted to establish an electrical field in said fluid and said earth formations, at least three receiving means on said support member adapted to receive electrical energy transmitted through an equivalent number of different vertically disposed portions of said earth formations, said receiving means all being of like character and at least one of said receiving means being located adjacent said transmitting means at a distance such that electrical energy transmitted through said fluid essentially masks the energy transmitted through said earth formations, means on said support member adapted to impede the transmission of electrical energy through said fluid and centralizing means on said support member for centralizing said means adapted to impede the transmission of electrical energy through said fluid.

13. Apparatus in accordance with claim 12 wherein the centralizing means comprises two resilient centralizing elements located at the upper and lower ends of the support member respectively.

14. Apparatus in accordance with claim 12 wherein the means adapted to impede the transmission of electrical energy through the fluid comprises at least one flat ring of non-conducting material, said ring being secured to the support member at the circumference of the inner diameter and having an outside diameter slightly smaller than the diameter of the well bore.

References Cited in the file of this patent

UNITED STATES PATENTS

2,220,070	Aiken	Nov. 5, 1940
2,268,138	Evjen	Dec. 30, 1941
2,304,051	Beers	Dec. 1, 1942
2,388,896	Aiken	Nov. 13, 1945
2,564,861	Sherborne	Aug. 21, 1951
2,669,688	Doll	Feb. 16, 1954
2,729,784	Fearon	Jan. 3, 1956
2,761,103	Doll	Aug. 28, 1956
2,782,364	Shuler et al.	Feb. 19, 1957

OTHER REFERENCES

"Exploration Physics" by Jakosky, 1950, First edition, fourth impression, by Trija-Publishing Company, Gayley Avenue, Los Angeles 24, California, pages 1027-1029.