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METHOD AND APPARATUS FOR CONTINUOUS EXPLORATION OF BORE HOLES

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2 Sheets-Sheet 1

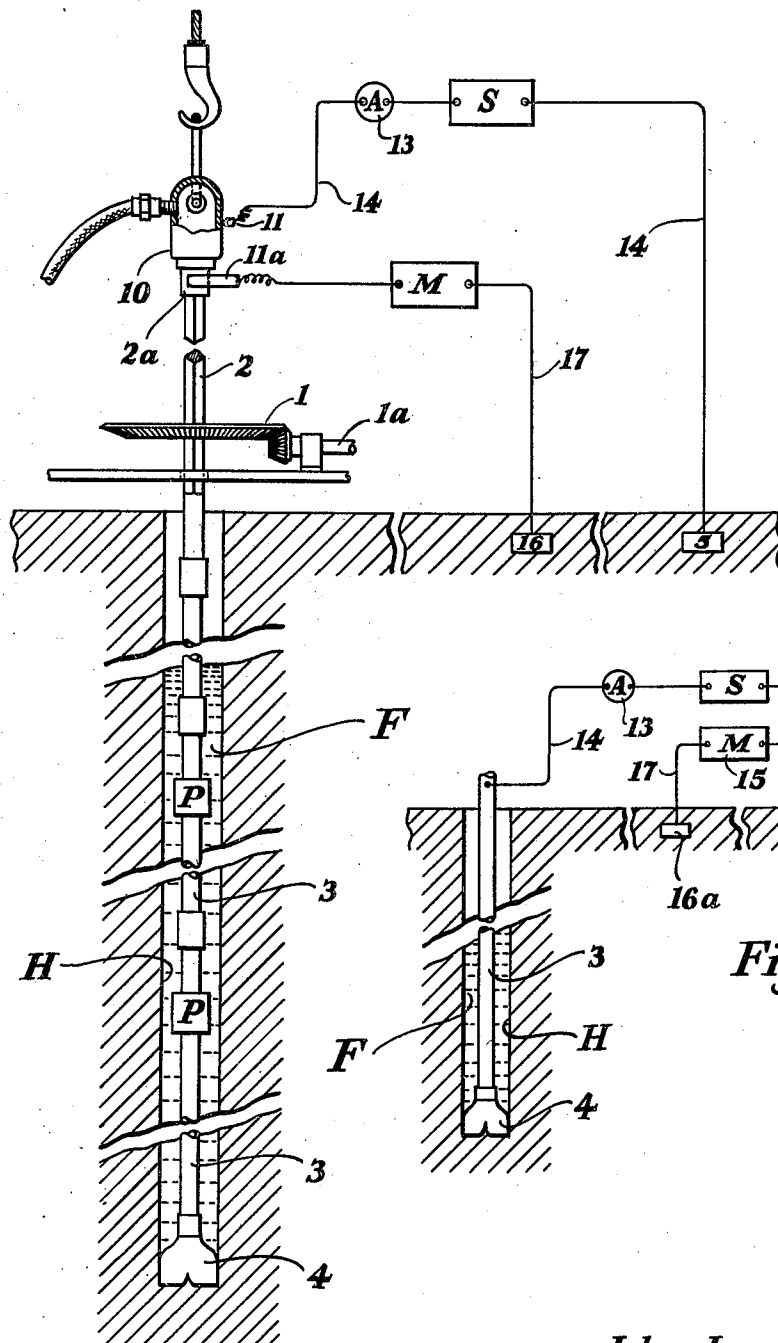


Fig. 1.

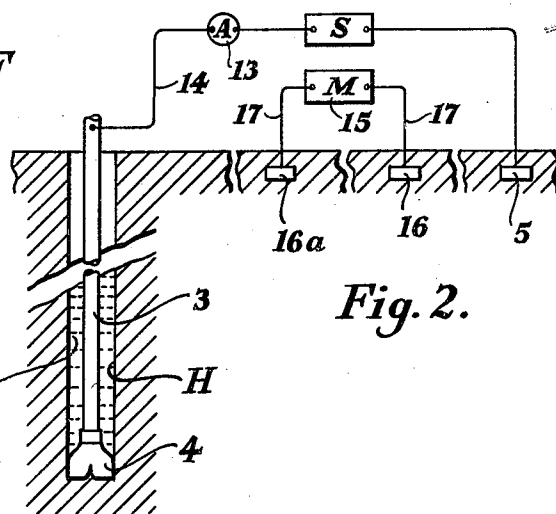


Fig. 2.

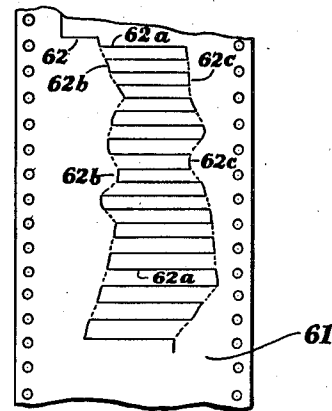
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UNITED STATES PATENT OFFICE

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METHOD AND APPARATUS FOR CONTINUOUS EXPLORATION OF BORE HOLES

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Application December 21, 1938, Serial No. 247,008

7 Claims. (Cl. 175—182)

This invention relates to an electrical method and apparatus for determining the character of the strata encountered at different depths by a drill bit during the drilling of a bore hole.

5 A prior method, which employs a drill pipe having an insulated internal conducting tube, or an insulated conductor extending down inside of a drill pipe, and a bit which is insulated from the drill pipe, has been suggested for this work.

10 With such an arrangement the current flows from this insulated bit into the strata and through the earth to the other terminal of the current circuit which is located at the surface of the ground near the mouth of the hole, or it may

15 be the drill pipe itself. Suitable measuring instruments are included in this circuit for measuring variations in current and/or potential as the bit descends the hole. After repeated and extensive tests at commercial operations the method has proven to be of limited use due to the

20 difficulty of properly insulating the drill pipe from the bore hole itself, or of passing an insulated wire down the inside of the drill pipe. Another practical difficulty in the latter method is to obtain proper insulation of the bit from the

25 drill pipe. Materials having the desired insulating qualities do not usually possess sufficient mechanical rigidity and ruggedness to withstand the severe conditions encountered in drilling work. In the method which is described in this

30 invention, these practical difficulties have been overcome, and in addition a simplified method of operation provided, which gives greater accuracy.

35 This application is a continuation-in-part of my application Ser. No. 112,207, filed November 23, 1936.

An object of the present invention is to provide a method and apparatus which will give a visible,

40 instantaneous, and preferably permanent record at the surface, as the drilling operations progress. Such records are of great value during drilling operations, especially in areas where the drilling must be stopped at a known horizon or strata,

45 as for instance when drilling into a high pressure oil sand, or when drilling through an oil sand, and where water may be encountered by a stratum underlying the oil sand. By means of the present method and apparatus suitable indicating and signaling means may be located on

50 the surface of the ground and the drilling operations supervised more intelligently.

55 Another object of the invention is to provide an advantageous method and apparatus for measur-

ing the electrical conductivity of the strata while utilizing either direct or alternating currents.

A further object of the invention is to provide means for measuring the vertical component of the natural earth potentials and other potentials while minimizing the effect of the horizontal component of the natural earth currents on such measurements.

According to this invention a direct, alternating or other suitable electric current is passed through an electric circuit which includes the drill stem and drill bit of a conventional drilling apparatus within a bore hole as one electrode, another electrode connected to the earth at a position laterally removed from the bore hole, and the portion of the earth included electrically between the electrodes; and a measurement is taken which involves the potential difference between two points whose potential difference changes with variations in the path of the current flowing between the drilling apparatus or bore hole electrode and the other or distant electrode. In the preferred embodiments of the invention described herein, this potential measurement is taken between two points spaced from one another along the path of current flow through the earth. The measurement is then repeated with the drill bit located at different depths within the bore hole in order to determine variations in the character of the strata encountered at different depths by the drill bit.

The above-mentioned other electrode is sufficiently removed from the bore hole so that changes in the electrical characteristics of the formation adjacent the drill bit will produce variations in the measurements. The positioning of this other electrode is an important feature of this invention. In general, it may be stated that when this other electrode is connected to the earth's surface it is preferably spaced from the bore hole by a distance which is comparable to the depth of the drill in the hole, for example, on the order of one-third or more the depth to which the drill bit is to be extended during any one set of measurements. The advantages of such an arrangement of the energizing electrodes or the equivalents thereof have been brought out fully in my pending application Serial No. 55,600, filed December 21, 1935. It may be seen that if the earth was to be energized between the drill bit and another electrode located closely adjacent the bore hole, or between the drill bit and a direct connection to the surface casing, as shown by the prior art, the current would flow largely between the near surface, and surface, drilling

apparatus, and the adjacent surface electrode. Under such conditions a sufficient portion of the current would not flow from the drill bit itself to give a readable or detectable change in the measured quantity as the different strata are encountered by the drill bit.

The term "measurements involving potential," as used throughout the specification and claims, is meant to include the direct measurement of a potential difference, the measurement of the relation between the energizing current and a potential difference, as for example with an apparatus of one of the types shown in my copending applications Serial No. 162,635, filed September 7, 1937, and Serial No. 172,009, filed October 30, 1937, or, when alternating current is used, the measurement, as one example, of the phase angle between the current in the energizing circuit and the potential difference between the two points utilized in the measurement. An apparatus for obtaining comparable phase-angle measurements is shown in my Patent No. 2,038,046.

In any electrical survey, when a measurement is taken while the earth is energized by an electric current, the final interpretation of the measurements depends not only upon the magnitude of the effect created by the energizing current but also upon the magnitude or some other characteristic of the energizing current. Hence, it will be understood that throughout the specification and claims where mention is made of measurements involving the potential difference, it will also be understood that the necessary information regarding the energizing current will also be obtained. Such information regarding the current may be obtained by directly measuring the current or by controlling its magnitude as by keeping it substantially constant for example, or by directly measuring the ratio between the energizing current and the potential difference.

As stated above, in practicing this invention the earth is energized by using the drilling apparatus as one electrode, and it is not necessary for the drill bit to be insulated from the drill stem. Thus the energizing circuit may be substantially the same as shown in my above-mentioned copending application Serial No. 112,207 and also in my copending application Serial No. 129,839, filed March 9, 1937, now issued as Patents No. 2,153,802 and No. 2,150,169 (Re. 21,102) respectively. This invention may be practiced in bore holes in which the hole is filled or partly filled with a conductive liquid medium, such as an ordinary water clay mud drilling fluid in a manner comparable to that described in said copending application Serial No. 129,839, or with a drilling fluid of relatively low conductivity such as an oil clay suspension, or other oil or drilling fluids of low conductivity, in a manner comparable to that described in said copending application Serial No. 112,207.

Further objects and advantages of the invention will become apparent as the description proceeds.

I have diagrammatically illustrated apparatus according to my invention in the accompanying drawings, in which:

Fig. 1 is a vertical cross-section of a portion of the earth illustrating the essential parts of a conventional rotary drilling apparatus in a bore-hole along with a circuit diagram according to my invention;

Fig. 2 is another diagrammatic vertical section illustrating a modified circuit arrangement;

Fig. 3 is a diagrammatic vertical cross-section of a portion of the earth showing a circuit arrangement which may be used to alternately measure the natural earth potential and the combined natural earth potential and the potential created by the flow of energizing current; in this case a cable drilling arrangement is shown, but the circuit arrangement is equally adapted to the rotary drilling equipment shown in the other figures;

Fig. 4 illustrates a record which may be obtained with the apparatus shown in Fig. 3; and

Fig. 5 is a diagrammatic cross-section illustrating a modified circuit arrangement which may be used to obtain measurements comparable to the measurements obtained with the apparatus shown in Fig. 3.

Fig. 1 illustrates the application of this invention to the conventional rotary system of drilling. In this figure, the rotary table 1 is connected to a proper source of motive power through shaft 1a. The rotary table, by means of the Kelly joint 2 transmits a rotary motion to drill stem 3 extending within a bore hole H. At the end of the drill stem is a drilling bit 4. The Kelly joint is supported at its upper end by a swivel-head 10. These parts constitute the usual type of rotary drilling equipment and need not be described in detail herein. A connection terminal 11 is in electrical contact with the swivel-head and associated drilling mechanism including the drill stem 3 and bit 4 and is associated with a suitable electrical energizing circuit, such as hereinafter described, for establishing an electrical circuit through the earth between the drilling apparatus and another electrode connected to the earth at a position remote from the bore hole.

The present invention is also applicable to various types of rotary drilling equipment and drilling bits, including various devices for obtaining rock samples, and to core bits. In addition, the invention may be applied to cable drilling apparatus wherein a heavy bit assembly impacts and cuts into the earth by being alternately raised and lowered on a steel cable. This invention may also be applied to hydraulic drilling methods employing a pipe, extending into the bore hole, from which water under high pressure is being discharged. In short, the method and apparatus of this invention may advantageously be employed with any exploring and/or drilling apparatus which is constructed of, or employs, electrically conductive materials.

Electrical connection to the rotary drill stem may be made by means of terminal 11, as above described and the other contact to the earth is made by means of a suitable surface electrode 5, preferably of large contact area, placed a considerable distance from the hole. This distance is preferably one-third (or more) of the depth which the drilling apparatus extends within the bore hole. In any case, the position of this distant electrode is sufficiently removed from the drill hole so that an appreciable portion of the current will pass through the drill bit 4 and through the earth formation adjacent the bit. The distant electrode 5 should be firmly imbedded in the earth in such a manner as to minimize the contact resistance. I have found that the electrode should preferably be placed a distance of two to five feet below the surface of the ground. The casing of a distant well may be utilized as a distant electrode, or a suitable electrode of extended surface area may be lowered

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into contact with the water or other conductive fluid in a distant well for this purpose.

A current source S and an indicating or recording ammeter 13 are shown connected in series between the terminal 11 and the electrode 5 through the agency of a suitably insulated conductor 14. The current source S may comprise any controllable source of direct or alternating current of either high or low frequency, commutated direct current, or pulsating current, or any other suitable source of current. A potential-responsive measuring means M such as a conventional potentiometer is shown connected between an earthed potential electrode 16 and a sliding terminal 11a in contact with the kelly 2 through the agency of a suitable insulated conductor 17. The kelly 2 is shown provided with a cylindrical portion 2a providing a slip ring for the contact 11a. This provides good electrical contact to drill stem and drill bit. Connection can of course be made directly to terminal on the swivel head 10. If a ratio measuring instrument is used for the measuring means M, for example one of the instruments described in my above-mentioned copending applications Serial Nos. 162,635 and 172,009, the current circuit is also connected to the measuring means M. For example, one of the current conductors 14 would be opened and the open ends connected through the instrument M. The electrode 16 is preferably located within the path of current flow through the earth between the drilling apparatus and the distant energizing electrode 5, and at a position spaced from the drilling apparatus. It may be located in the same direction from the bore hole as the energizing electrode 5. The electrodes 5 and 16 may be located fairly close to one another, on the order of 100 feet for example, without interfering with the proper functioning of the apparatus, but they are preferably located at a considerable distance from one another. For example, I may locate the electrode 16 in the opposite direction from the bore hole to the electrode 5. It should be understood, however, that the potential electrode 16 may be located considerably nearer to the drill hole than it is possible to locate the current electrode 5 and still obtain satisfactory operation of the apparatus.

According to one practice of the invention, the source of current S is set in operation and energizing current is caused to pass in the energizing circuit which includes drill stem 3 and drill bit 4 as one electrode, the energizing electrode 5 as the other electrode, and the portion of the earth included electrically therebetween. It will be seen that when an electric current is passed through the earth between the drilling apparatus and the distant electrode 5, as by means of the above-described energizing circuit, the current will in some cases flow between the earth and the drilling apparatus throughout substantially the entire length thereof, particularly when the bore hole contains a conductive fluid medium such as the aqueous drilling fluid ordinarily employed in rotary drilling operations, as described in said copending application Serial No. 129,839. However, this flow between the drill stem and the earth throughout the length of the drilling apparatus is not so pronounced when insulating drilling fluids are used such as brought out in said application Serial No. 112,207. A suitable drilling fluid which may fill or partly fill the bore hole is shown at F, and such fluid may be of either the conductive or poorly conductive type. This liquid medium F is maintained in the bore

hole around the drill stem 3 which is exposed to electrical contact with such medium throughout substantially its entire length. It will be noted that the drill stem 3 is shown provided with protectors P which may be of a type that is commercially available and are preferably of insulating material. These protectors tend to minimize the chance contacts of the drill stem with the wall of the bore hole and tend to prevent erratic variations in the measurements. However, such protectors are not essential to the practice of this invention and are shown only as a means of minimizing variations in the measurements.

In any event, if the distant electrode is sufficiently removed from the bore hole, an appreciable portion of the current will flow throughout substantially the entire length of the drill stem or other drilling apparatus extending within the bore hole, and through the strata adjacent the lower end of the drilling apparatus. It is this current flow, which is appreciable if the distant electrode is removed a sufficient distance from the bore hole, which gives electrical variations indicative of the nature of the strata adjacent the lower end of the drilling apparatus, as the drilling apparatus is moved to different depths. The resulting changes in current distribution produce variations in the magnitude and distribution of the potential field created by the current flow between the drilling apparatus and the distant energizing electrode and produce variations in the potential difference between the terminal 11a and the electrode 16 which are indicative of variations in the electrical properties of the strata encountered by the drill bit at different depths. For practical purposes the terminal 11a may be considered to be at substantially the same potential as the drill bit 4.

Thus the variations in the measurements will be produced by changes in the electrical characteristics of the formation adjacent the drill bit and when the variations in the measurements obtained on the potential-responsive measuring means M are correlated with the corresponding values of current in the energizing circuit as may be obtained from the ammeter 13, for example, valuable information regarding the character of the strata encountered by the drill bit at different depths may be obtained.

If direct current is employed, the readings obtained will be a function of the resistance of the formations adjacent the drill hole, while if alternating current is employed, the readings will be a function of the impedance of such formations. Broadly, it may be said that the measurements serve to indicate variations in the conductivity of the formations, the term "conductivity" being considered herein as including either straight conductance (the reciprocal of resistance) in the case of direct current, or admittance (the reciprocal of impedance) in the case of alternating current.

Measurements are preferably made continuously as the drilling proceeds in order to give a complete history of the drilling operations and to allow recognition of the various marker strata encountered by the drill bit as the drilling apparatus is extended to different depths in the bore hole and penetrates the formations successively at different depths. As brought out in the above-mentioned copending applications, the electrical information may be continuously recorded on a time- or depth-operated recording chart such as shown in said applications, so that the information obtained may be used not only as an electri-

cal record of the characteristics of the formation traversed by the bore hole but also as a record of the operations of the drilling crew showing the progress made in drilling and the time required to perform various operations such as removing the drilling apparatus from the hole.

The measurements should begin, however, at a time when the strata exhibit characteristic electrical changes which may be employed for correlation purposes. In some cases, important electrical markers (strata which may readily be recognized by characteristic changes in electrical properties) manifest themselves many hundreds of feet above the oil sand, while in other areas important markers are encountered adjacent to the oil sand. In metal mining operations, the measurements should begin prior to the time the drill penetrates the mineral-bearing formations. For location of water-bearing horizons the measurements also should begin prior to the time the bit penetrates the water-bearing formations.

Referring to Fig. 2, a modified apparatus arrangement is shown in which the energizing circuit corresponds to the energizing circuit illustrated in Fig. 1 and the potential-responsive measuring means M is connected between the potential electrode 16 and a second potential electrode 16a, both connected to the surface of the earth and spaced from one another along the path of current flow through the earth. Thus the conductor 17 instead of being connected to the terminal 11a which is connected to the drill stem 3 is connected to the additional potential electrode 16a. With the arrangement illustrated, the electrodes 5, 16, and 16a are shown arranged substantially along a single straight line which passes through the bore hole H and the electrodes 16 and 16a are positioned between the bore hole and the distant energizing electrode 5. It is to be understood that this particular arrangement of the electrodes is not necessary to the satisfactory operation of the apparatus, but that the electrodes 16 and 16a may be connected between any two points whose potential difference changes with variations in the path of the current flowing between the drilling apparatus and the distant energizing electrode 5. It is preferable, however, to have the potential electrodes located at a considerable distance from the energizing electrode 5. For example, they may be located in the direction from the bore hole opposite to the direction of the electrode 5.

Measurements may be taken with this apparatus in exactly the same manner as with the apparatus shown in Fig. 1. Thus the earth is energized between the drilling apparatus and the electrode 5, and measurements are taken involving the potential difference between electrodes 16 and 16a with the drill bit 4 located at different depths within the bore hole.

The measurements obtained with the apparatus shown in Figs. 1 and 2 will in general be affected by the varying natural earth potentials, and in Fig. 3 I have shown a way for minimizing the effects of such potentials on the final measurements. In this figure a churn or cable drilling apparatus is illustrated and is shown as comprising a heavy bit assembly including a drill bit 44 and a connected drill stem 45 suspended within the bore hole H by a cable 45a. With such an arrangement the bit is alternately raised and lowered by the cable 45a by means not shown, so that as the bit is lowered it impacts the earth and produces the hole H. The ener-

gizing circuit is shown as comprising a switching means 54 and power source S connected in series between distant energizing electrode 23 and the drilling assembly including the drill bit 44 through insulated conductors 70 and 71. The conductor 71 is connected by a clamp 71a to cable 45a which provides electrical connection to the drill bit 44. The source S is preferably a constant current generator provided with suitable manual or automatic means for maintaining a constant current reading on the ammeter A during the times of current flow, although any other suitable controlled source may be used. The switching means 54 may comprise stationary quadrants 55 and 56 and a rotor bar 57 connected to a suitable time-operated shaft so that as the time-operated rotor 57 turns, connection will first be established between the quadrants 55 and 56 by the bar 57 and then broken so that periods of current flow are alternated with periods of no current flow.

The potential circuit is somewhat modified, and is shown as comprising a potentiometer 52 and measuring means M connected in series with potential electrode 22 and the drilling assembly by conductors 72 and 73, respectively. The conductor 73 is shown connected to cable 45a through clamp 73a. The natural earth potential between the drill stem and the electrode 22 may now be measured with the portion of the electrical circuit described above. The electrode 22 may be located with respect to the bore hole and the distant energizing electrode 23 in any of the manners described in connection with the electrodes 5 and 16.

It will be understood that the circuit arrangement above described is equally adapted to use with rotary drilling equipment as illustrated in Figs. 1 and 2 for example. Thus the conductors 71 and 73 instead of being connected to the cable 45a would be electrically connected to the drill stem 3 illustrated in Fig. 1, for example.

In order to establish a suitable zero level on the record of the recording meter M which is indicated at 61 in Fig. 4, the potentiometer 52 may be adjusted to bring the indication of the earth potential to any convenient point on the recording medium 61. It will be appreciated that as the bit 44 bores into the earth, the potential will vary or drift and it may be necessary from time to time to readjust the potentiometer 52 to keep the potential readings on the record; also when bad ground currents prevail it may be necessary to reverse the polarity of the battery 51 in some instances to maintain the desired control of the recording.

When connection is established between the quadrants 55 and 56 the measuring means M will give indications which are indicative of the potential between the drilling apparatus and the electrode 22 as influenced by the current flow from 23 to the drilling apparatus; these indications will also be influenced by the natural earth potential. When connection is broken between said quadrants the meter M will give indications of natural earth potentials as above described.

Referring particularly to Fig. 4, I have shown an example of a record which may be obtained with the apparatus shown in Fig. 3. The solid line 62 on the recording tape 61 represents the path of the stylus of the measuring means M; the substantially horizontal portions of said record, indicated at 62a, represent the interval at which the rotor 57 either makes or breaks with the quadrants 55 and 56. For example, the short

portions of the recording on the left side, indicated at 62b, may represent the value of the natural earth potential during an interval in which the rotor 57 of the switching means 54 does not establish contact with the quadrants 55 and 56; when the rotor 57 contacts said quadrants the stylus will move across the record as at 62a and trace a record, for example of potential, at 62c for the length of time said connection is maintained. At the end of said time the contact will be broken and the stylus will move to the left along 62b and trace the curve 62a. Thus it may be seen that by dotting in the lines between the adjacent portions of the curves 62b and 62c, a continuous record of the earth potential and potential indicative of earth conductivity or other property and the nature and characteristics of the strata may be plotted simultaneously on the single recording medium.

It will be appreciated that suitable compensating networks may be inserted in the circuit of the measuring means M and in operative association with the switching means 54 for adjusting the relative positions and amplitudes of the earth potential curve 62b and potential curve 62c as will readily be apparent to those skilled in the electrical art.

It will be apparent that the conductor 73 may be connected to a suitable potential electrode comparable to the electrode 16a shown in Fig. 2 instead of to the drilling apparatus. If such is the case measurements will be made between two potential electrodes as shown in Fig. 2.

It will be appreciated that the power source S shown in Fig. 3 may be alternating current source in which case the recording means M may be replaced by a suitable direct current instrument for obtaining natural earth potential readings and an alternating current instrument for obtaining alternating current potential readings. Circuit arrangements suitable for obtaining such readings are shown and described in Patent No. 2,132,807 to Rust, Jr., et al.

An alternative arrangement for minimizing the effects of natural earth potential on the final measurements is illustrated in Fig. 5. Distant potential electrodes 21 and 22 are located at a considerable distance from the drill hole H and are shown connected through suitable insulated conductors 41 and 42 to a common conductor 43 which is connected to the variable tap of a potentiometer 52. A drill bit 74 is shown in contact with the bottom of the hole H and is in electrical connection with a drill stem 75 which is connected through a suitable conductor 46 to one side of a potential responsive measuring device M such as a conventional indicating or recording potentiometer, the other side of said measuring device being connected to the other side of the potentiometer 52 through a conductor 47. The bore hole H may be filled or partly filled with a fluid F which may be conductive or it may be partly insulating as described in the above-mentioned application Serial No. 112,207. The potential between the conductors 43 and 47 may be made variable by connecting a battery 51 across the potentiometer and varying the potentiometer 52 according to well-known procedures.

The utilization of two or more potential electrodes connected together at a common point, such as the electrodes 21 and 22, connected together by the conductors 41 and 42 to the common conductor 43, is one important feature of this invention. Such an arrangement tends to eliminate potential variations due to changing

earth currents, which currents are ordinarily a varying source of error and are present at all times, making it practically impossible to duplicate survey results. This feature has been particularly pointed out in my pending application Serial No. 103,038, filed September 28, 1936, and in my above-mentioned copending application Serial No. 112,207, and it will suffice to say that the reference electrodes such as 21 and 22 should be spaced with respect to hole H and connected together in such manner that the horizontal component of the natural earth currents in the neighborhood of the bore hole will have a negligible effect on the reference potential no matter what the direction or magnitude of the earth currents. In areas where extreme variations in earth currents are encountered, more than two potential electrodes may be advantageously employed. It has been found that normal earth currents flow substantially horizontally, and have a very minor vertical component. In the example illustrated in Fig. 5, the electrodes 21 and 22 are shown substantially equidistant from the drill hole H and at a considerable distance therefrom, and that 21, 22, and H are substantially in a line with one another. The electrodes 21 and 22 may be disposed preferably symmetrically with respect to the bore hole, on a straight line at right angles to the straight line joining the bore hole and the distant energizing electrode.

The natural earth potential between the reference potential supplied by the points 21 and 22 and the drill stem 75 may now be measured with the portion of the electrical circuit described above. Since the electrodes 21 and 22 are located at a considerable distance from the drill hole and are connected together through conductors 41 and 42, the juncture of said conductors and the conductor 43 is at a more or less average potential of the points 21 and 22 and is considered as a reference potential, and measurements may be taken with the measuring device M, which may comprise a recording potentiometer, which are indicative of the vertical component of the earth potential at the position of the drill bit 74.

I have also shown a distant energizing electrode 23 connected through an insulated conductor 53 including an ammeter A to a variable potential power source S, the other side of said source S being connected to one side of a switching means 54 and the other side of said switching means being connected through a conductor 58 to the conductor 46 which is connected to the drill stem 75.

The distant energizing electrode 23 is placed at a considerable distance from the bore hole H, for example a distance equal to or greater than one-third the depth to which the bit 74 is carried, so that sufficient energy will flow in the earth to create a measurable potential between electrodes 21 and 22, and the bit 74 or drill stem 75. The electrodes 21 and 22 may be disposed, preferably symmetrically with respect to the bore hole, on any one of a number of straight lines bearing any angular relation to the straight line passing through the bore hole H and the electrode 23. For example, the electrodes 21 and 22 may be disposed on a straight line perpendicular to the straight line passing through the bore hole and the electrode 23. At least one, and preferably both, of the electrodes 21 and 22 are located within the path of current through the earth between the drilling apparatus and the electrode 23.

It may be readily seen that current flow through the earth between the drilling apparatus and the electrode 23 will influence the potential of adjacent points on the surface of the earth and that the potential of any of said last-named points will be a function of the current distribution through the earth, which is indicative of the nature of the strata, and a function of the current in said circuits. By maintaining a constant current through the earth circuit interpretation will be greatly simplified, although results may be interpreted if variations in current are recorded along with potential measurements. If variable current energization is employed, the meter A should preferably be of a recording type, to allow proper interpretation of the potential record made by recording meter M.

It is not entirely necessary to use the switching means 54 so as to obtain alternate measurements involving the natural earth potential alone when no current is flowing and measurements involving the combined created and natural earth potentials during the flow of energizing current as described in connection with Figs. 3 and 4, since the use of the reference potential electrodes 21 and 22 minimizes the effects of the natural earth potentials. However, alternate measurements may be taken in the same manner as described in connection with Fig. 3 to obtain a record which may be entirely comparable to the record illustrated in Fig. 4.

Methods and apparatus in which measurements are taken indicative of the potential during successive energizing current pulses and during the intervals between such current pulses as described above are more fully described and claimed in my copending application Serial No. 230,963, filed September 21, 1938.

It is to be understood that the circuit arrangements illustrated in Figs. 1, 2, and 5 are equally adapted for use with cable drilling equipment as illustrated in Fig. 3, in which case the circuit connections which are made to the drill stem either directly or through the swivel-head are made to cable 45a as illustrated in Fig. 3.

In general, the magnitude of the variations in the measurements produced by changes of given magnitude in the electrical characteristics of the strata will change as the drilling apparatus is extended to greater depths. For example, a given change in characteristics of the strata may give a variation of ten per cent in the measurements when the drill bit is at one depth and only a five per cent change when the drill bit is at a greater depth. Hence, this phenomenon must be taken into consideration if it is desired to directly compare the measurements at relatively shallow depths with the measurements at relatively great depths. In practice the measurements at different depths may be multiplied by empirical factors based upon experience in the area, in order to permit such comparison.

I claim:

1. In the drilling of a bore hole with a drilling apparatus comprising a drill stem extending within the bore hole and a drill bit electrically connected to said drill stem at the lower end of said drill stem, the method of determining the character of the strata encountered at different depths by the drill bit during the drilling of said bore hole, which comprises: passing a controlled electric current through an electric circuit including the drill stem and the drill bit as one electrode, another electrode connected to the earth at a position removed from the bore hole, and the portion of the earth included electrically

between said electrodes; taking a measurement involving the potential difference between two points whose potential difference changes with variations in the path of the current flowing between said electrodes; and repeating such measurement with said drill bit located at different depths within the bore hole, while maintaining a liquid medium in the bore hole around said drill stem, said drill stem being exposed to electrical contact with said liquid medium throughout substantially its entire length and said other electrode being sufficiently removed from the bore hole so that changes in the electrical characteristics of the formation adjacent the drill bit will produce variations in said measurements.

2. In the drilling of a bore hole with a drilling apparatus comprising a drill stem extending within the bore hole and a drill bit electrically connected to said drill stem at the lower end of said drill stem, the method of determining the character of the strata encountered at different depths by the drill bit during the drilling of said bore hole, which comprises: passing a controlled electric current through an electric circuit including the drill stem and the drill bit as one electrode, another electrode connected to the earth at a position removed from the bore hole, and the portion of the earth included electrically between said electrodes; measuring the potential difference between two points whose potential difference changes with variations in the path of the current flowing between said electrodes; and repeating such measurement with said drill bit located at different depths within the bore hole, while maintaining a liquid medium in the bore hole around said drill stem, said drill stem being exposed to electrical contact with said liquid medium throughout substantially its entire length and said other electrode being sufficiently removed from the bore hole so that changes in the electrical characteristics of the formation adjacent the drill bit will produce variations in said measurements.

3. In the drilling of a bore hole with a drilling apparatus comprising a drill stem extending within the bore hole and a drill bit electrically connected to said drill stem at the lower end of said drill stem, the method of determining the character of the strata encountered at different depths by the drill bit during the drilling of said bore hole, which comprises: passing a controlled electric current through an electric circuit including the drill stem and the drill bit as one electrode, another electrode connected to the earth at a position removed from the bore hole and the portion of the earth included electrically between said electrodes; measuring the potential difference between a pair of potential electrodes connected to the earth at two points whose potential difference changes with variations in the path of the current flowing between said electrodes; and repeating such measurement with said drill bit located at different depths within the bore hole, while maintaining a liquid medium in the bore hole around said drill stem, said drill stem being exposed to electrical contact with said liquid medium throughout substantially its entire length and said other electrode being sufficiently removed from the bore hole so that changes in the electrical characteristics of the formation adjacent the drill bit will produce measurable variations in said measurements.

4. In the drilling of a bore hole with a drilling apparatus comprising a drill stem extending within the bore hole and a drill bit at the lower

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end of said drill stem, the method of exploring the strata traversed by the bore hole, which comprises: passing an electric current through the earth between the drill stem and drill bit as one electrode and another electrode connected to the earth at a position remote from the bore hole, and measuring an electrical potential associated with such current flow; interrupting said current flow and taking a measurement of natural earth potential while said current flow is so interrupted; and repeating the steps of alternately measuring one potential during current flow and the other potential when the current flow is interrupted as said drill stem is extended to different depths, said other electrode being sufficiently distant from said bore hole so that variations in the measured electrical potential associated with the flow of such current will be produced by changes in an electrical characteristic of the different portions of the earth included electrically between said electrodes as said drill bit is moved to different depths in said bore hole.

5. An apparatus for use in determining the character of the strata encountered at different depths by the drill bit during the drilling of a bore hole containing a liquid medium, which comprises: an electrode comprising a drill stem and the drill bit electrically connected to the drill stem and in electrical connection with the earth within said bore hole, said drill stem being exposed to electrical contact with said liquid medium throughout substantially its entire length; an electrode connected to the surface of the earth at a position remote from said bore hole; a controllable source of electric current connected to said drill stem and to said last-named electrode for passing an electric current through the earth between said electrodes; and potential-responsive measuring means connected between two points whose potential difference changes with variations in the path of the current flowing between said electrodes for indicating changes in an electrical characteristic of the earth included between said electrodes when said drill bit is located at different depths, said other electrode being sufficiently distant from said bore hole so that variations in said measurements will be produced by changes in an electrical characteristic of the different portions of the earth included electrically between said electrodes as said drill bit is moved to different depths in said bore hole.

6. An apparatus for use in determining the character of the strata encountered at different depths by the drill bit during the drilling of a bore hole containing a liquid medium, which

comprises: an electrode comprising a drill stem and the drill bit electrically connected to the drill stem and in electrical connection with the earth within said bore hole, said drill stem being exposed to electrical contact with said liquid medium throughout substantially its entire length; an electrode connected to the surface of the earth at a position remote from said bore hole; a controllable source of electric current connected to said drill stem and to said last-named electrode for passing an electric current through the earth between said electrodes; and potential-responsive measuring means connected between a pair of electrodes electrically connected to the earth at two points whose potential difference changes with variations in the path of the current flowing between said electrodes for indicating changes in an electrical characteristic of the earth included between said electrodes when said drill bit electrode is located at different depths, said other electrode being sufficiently distant from said bore hole so that variations in said measurements will be produced by changes in an electrical characteristic of the different portions of the earth included electrically between said electrodes as said drill bit is moved to different depths in said bore hole.

7. An apparatus for use in determining the character of the strata encountered at different depths by the drill bit during the drilling of a bore hole, which comprises: an electrode comprising a drill stem and the drill bit positioned within a bore hole and in electrical connection with the earth therein; an energizing electrode connected to the surface of the earth at a position laterally removed from said bore hole; power supply means connected to said energizing electrode and to said drill stem through switching means operable to alternately connect and disconnect said power supply means to said drill stem; potential electrode means in electrical contact with the earth; and measuring means connected between said last-named electrode means and said drill stem for indicating variations in the natural earth potentials between said drill stem and said other electrodes as said drill bit is moved to different depths in the bore hole, said measuring means being operable to indicate variations in natural earth potentials when said switching means is in disconnected position and operable to indicate variations in an electrical characteristic of the earth included between said energizing electrodes when said switching means is in connected position, as said drill bit is moved to different depths within the bore hole.

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