

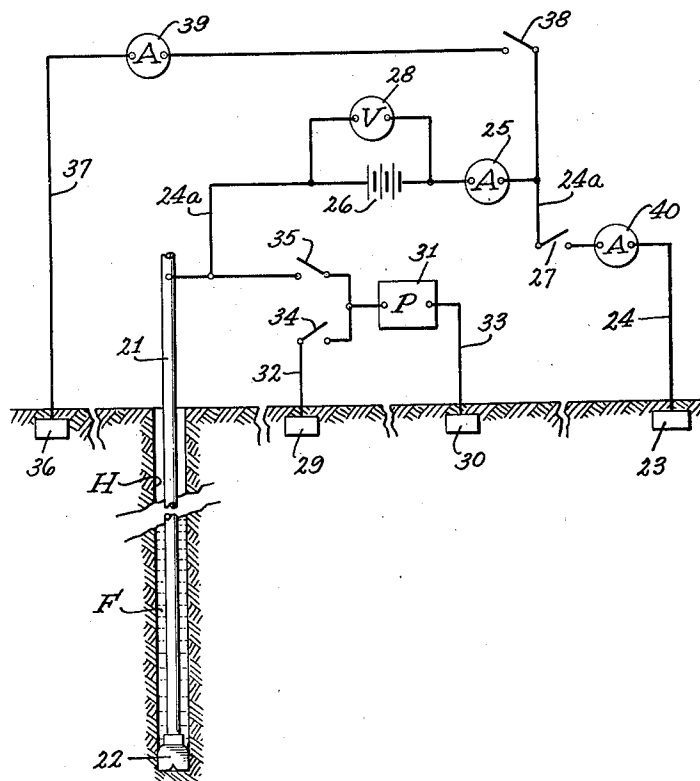
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METHOD FOR CONTINUOUSLY EXPLORING BOREHOLES

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METHOD FOR CONTINUOUSLY EXPLORING
BOREHOLES

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1 Claim. (Cl. 175—182)

This invention relates to the electrical exploration of the subsurface and pertains more particularly to a method for determining variations in an electrical property of the strata at different depths traversed by a borehole during the drilling thereof.

The principal object of the invention is to provide a method for giving a visible, instantaneous, and preferably permanent record at the surface, as the drilling operations progress. Such records are of great value, especially in areas where the drilling must be stopped at a known horizon or strata, 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 the drilling operations may be supervised more intelligently.

Another important use of the invention is in connection with the small diameter holes employed in structural mapping. By this invention it is possible to obtain an electrical log of the hole, while it is being drilled; and this log may be correlated with similar logs from other holes for determining structural relationships at the various drill hole locations. The simultaneous mapping of structure during the drilling operation effects an important saving in time and expense.

A prior method has been suggested for determining the character of the strata traversed by the drilling apparatus as the drilling operation proceeds, which employs an insulated drill pipe, or an insulated conductor extending down inside a drill pipe, and a bit which is insulated from the drill pipe. The current flows from this insulated bit into the strata. The other terminal of the current circuit is at the surface of the ground near the mouth of the hole, or it may 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 difficulty of properly insulating the drill pipe from the borehole itself, or of maintaining 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 drill pipe. Insulating materials of this type are not usually of sufficient mechanical rigidity and ruggedness to withstand the severe conditions encountered in drill work. In the

method which is described in this invention, these practical difficulties have been overcome and a simplified method of operation is provided.

A particular object of this invention is to provide a method which utilizes a conventional form of drilling apparatus, which extends into a borehole and is exposed to electrical contact with the wall of the borehole substantially throughout its length, as an electrode in an electrical system for determining the nature and characteristics of the strata adjacent the lower end of said drilling apparatus, and does not require the insulating of one portion of the drilling apparatus from another.

A more specific object of the invention is to provide a method for determining variations in the inclination of the strata traversed by a borehole during the drilling thereof.

According to this invention, I pass a unidirectional electric current, either continuous or pulsating, through the earth between an electrode comprising a drilling apparatus extending within a borehole and another electrode connected to the earth at a position removed from the borehole as the drilling apparatus drills to different depths. During drilling operations it is customary to circulate a fluid suspension, generally referred to as "drilling mud," through the hole to flush out the cuttings. In general this fluid is more or less conductive and may comprise a water-clay suspension, which has a relatively high conductivity such as employed in my copending application Serial No. 129,839, filed March 9, 1937, now Patent No. 2,150,169, or it may comprise an oil-clay suspension or other relatively poorly conductive fluid medium such as employed in my copending application Serial No. 112,207, filed November 23, 1936, now Patent No. 2,153,802. Thus the drilling apparatus is exposed to electrical contact with the wall of the borehole throughout substantially its entire length, either through the drilling mud or by actual contact with the borehole wall, and there is a flow of electric current between the drilling apparatus and the earth throughout substantially the entire length of the drilling apparatus. As brought out in my above-mentioned copending applications as well as in my copending application Serial No. 247,008, filed December 21, 1938, now Patent No. 2,181,601, this flow of current substantially throughout the length of the drilling apparatus does not, as might be expected, completely mask the flow of current through the earth through the lower end of the

drilling apparatus comprising the drill bit. Thus there is a measurable flow of current through the lower end of the drilling apparatus, which is continuously contacting new material, and through the earth between the lower end of the drilling apparatus and the other electrode, and by taking a series of measurements as the drilling apparatus is extended to different depths I obtain data indicative of variations in an electrical characteristic of the path of this current flow.

The variations in this flow of current and the variations in the distribution thereof serve to indicate the changes in the strata cut by the drilling apparatus as it penetrates to different depths. Also, as brought out in the above-mentioned applications, the magnitude of the current flow depends to a certain extent upon the distance which the other electrode is removed from the borehole. In general, with the drilling apparatus located at a given depth, a larger proportion of the total current flows from the lower end of the drilling apparatus with increasing separation of the drilling apparatus and the other electrode.

The practice of my method as applied to the determination of variations in the inclination of strata traversed by a borehole during drilling thereof is best described in connection with the accompanying single figure of drawings. In this figure a drilling apparatus 21 provided with a drill bit 22 at the lower end thereof is shown extending within a borehole H with the drill bit 22 in contact with the bottom of the hole H. The illustration of the drilling apparatus is somewhat diagrammatic; however, the construction and mode of making electrical connection thereto is illustrated in greater detail in my Patents No. 2,150,169, 2,153,802, and 2,181,601, and does not form part of the present invention. The energizing circuit is shown as comprising an electrode 23 connected to the earth at a position removed from the borehole and connected through insulated conductors 24 and 24a to the drilling apparatus 21. Connected in circuit with the electrode 23 in the conductor 24a I have shown a suitable current measuring instrument 25 and a source of unidirectional current such as a battery 26. With the circuit arrangement described, upon closing switch 27 connecting conductors 24 and 24a, a unidirectional electric current may be passed through the earth between the electrode comprising the drilling apparatus 21 and the drill bit 22, and the electrode 23. Since the measurements are taken during drilling of the borehole, the drilling apparatus is exposed to electrical contact with the earth throughout substantially its entire length due to its actual contact with the walls of the borehole and also due to the conductive drilling fluid F which either fills or partly fills the borehole. Thus the current is caused to flow between the drilling apparatus and the earth throughout substantially the entire length of the drilling apparatus.

After the flow of this current has begun, the flow of the current from the drilling apparatus to the earth at positions above the bottom of the hole decreases for an appreciable time, from one to five minutes for example, and substantially stable electrochemical conditions are established at such positions. This phenomenon may be observed by measuring a decrease in the value of the current indicated by the current-measuring instrument 25, assuming for the purposes of illus-

tration that the potential of the current source 26 remains constant during this interval as by observing the reading of voltmeter 28 connected across the current source 26. This condition may also be observed by simultaneously measuring the relation between the current in the energizing circuit and the potential existing between a pair of potential electrodes connected to the earth at spaced positions and so located as to be appreciably influenced by the flow and distribution of current through the earth between the drill bit 22 and the electrode 23.

For example, I may connect potential electrodes 29 and 30 to the earth at positions spaced from one another and from the borehole H and the electrode 23, and connect them to a suitable potential-measuring instrument 31 such as a conventional potentiometer, through insulated conductors 32 and 33. By observing the readings of the potential instrument 29 and the current instrument 25 after closing switch 34 in conductor 32, with the drilling apparatus operating at different depths, the changes in magnitude and distribution of the current flow from the lower end of the drilling apparatus as from the drill bit 22 may be determined. It is not necessary to take potential measurements between a separate pair of potential electrodes, and I may take the measurements between one of the potential electrodes, for example electrode 30, and the drilling apparatus 21. For this purpose I may open switch 34 and close switch 35 so that the potential-measuring instrument 31 is connected between the drilling apparatus 21 and the electrode 30. These arrangements of apparatus are comparable to the ones illustrated in my above-mentioned copending application Serial No. 247,008.

The potential electrodes 29 and 30 are so located that the potential difference therebetween is affected by the magnitude and distribution of the current flowing between the electrode 23 and the drilling apparatus 21. Thus I may position these potential electrodes between the drilling apparatus and the electrode 23, for example, or they may be positioned on the opposite side of the drilling apparatus, which position is generally preferable, but the electrodes 29 and 30 are positioned as shown in order to simplify the drawing.

By employing a plurality of spaced energizing electrodes connected to the earth and to one another so that I may pass current through the earth between the drilling apparatus and a plurality of energizing electrodes, I obtain information concerning the inclination of the strata traversed by the borehole. For example, I may connect another energizing electrode 36 to the earth at a position spaced from the borehole H in the opposite direction from the electrode 23 and connect this electrode 36 through an insulated conductor 37 to the conductor 24a through a switch 38 so that upon closing both switches 27 and 38 the current supplied by the source 26 flows between the drilling apparatus and both the electrodes 23 and 36. With the current flowing through these electrodes I may measure the potential between the electrodes 29 and 30 or between the drilling apparatus and the electrode 30 by closing either switch 34 or 35 and determine the relation between the magnitude of the current as indicated by the ammeter 25 and the measured potential. As another example, I may determine the relation between the total current flowing through the drilling apparatus as

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indicated by the ammeter 25 and the applied potential as indicated by the voltmeter 28 when the switches 27 and 38 are closed and the current is flowing between the drilling apparatus and both of the electrodes 23 and 36.

As another example, I may insert a current-measuring instrument 39 in the conductor 37 and another current-measuring instrument 40 in the conductor 24. The relation between the current flowing through the electrode 23 as indicated by the instrument 40 and the applied potential as indicated by the voltmeter 28 is indicative of the resistivity of the earth materials in the current path between the electrode 23 and the drilling apparatus, while the relation between the current flowing through the electrode 36 as indicated by the instrument 39 and the applied potential is indicative of the resistivity of the earth materials in the current path between the drilling apparatus and the electrode 36. Either one of these values of resistivity may be used as a basis for determining the nature and characteristics of the earth formation penetrated by the drilling apparatus.

A comparison of these two values of resistivity will give information regarding the dip or inclination of the strata traversed by the drilling apparatus, since the value of the measured resistivity will be lower for the electrode located on the up-dip side of the hole than for the electrode located on the down-dip side. Thus, if the measured resistivity of the earth between the electrode 23 and the drilling apparatus is lower than between the electrode 36 and the drilling apparatus, it may be stated in general that the electrode 23 is on the up-dip side of the borehole H. Obviously, by using more than two current electrodes connected to the earth at different angular positions with respect to the borehole H, information regarding the strike as well as the dip of the strata may be obtained.

When taking a series of measurements with the drilling apparatus operating at successively greater depths it may be preferable to take separate series involving the measurements obtained on the instruments 39 and 40 at the different depths and then plot the indicated resistivity obtained in each series against the depth of the drill bit. By comparing the two curves so obtained, information regarding the variation in dip at different depths may be obtained.

I may also take dip measurements by using an additional set of potential electrodes, for example another set like the electrodes 29 and 30 placed on the opposite side of the borehole, and take measurements whereby the relation between the current in conductor 37 and the potential between these electrodes may be obtained and compared to the relation between the current in the conductor 24 and the potential between electrodes 29 and 30.

Obviously, each pair of current and potential measuring instruments may be replaced by a single ratio-measuring instrument such as that described in my copending application Serial Nos. 162,635 and 172,009 (the latter having issued as Patent No. 2,192,404), or such as shown in my Patent No. 2,137,650. I also may provide suitable well known means for controlling the flow of current through the earth between the drilling

apparatus and the other electrode or electrodes in the energizing circuits so that the current flow may be established at any desired value or varied in accordance with any established procedure.

The electrodes 23 and 36 are located at positions sufficiently removed from the borehole H so that after the current has flowed for a sufficient time to bring about the above-defined stable electrochemical conditions as evidenced by the stable high value of the indicated resistivity, the variations in the electrical properties of the material adjacent the lower end of the drilling apparatus will produce measurable variations in the measurements. This condition may be obtained usually by spacing these electrodes from 100 to 500 feet or more from the borehole. It is preferable to maintain these electrodes in fixed positions when current is flowing therethrough.

Instead of measuring the relation between current and potential as described above, I may use a conventional four arm bridge in which one arm comprises the earth between the drilling apparatus and one of the energizing electrodes, as described in my above-mentioned copending application Serial No. 129,829.

Throughout this specification and in the appended claim, a unidirectional current is meant to include certain types of alternating and pulsating currents as well as substantially steady or varying continuous currents, since all these types of currents may be employed for the purposes of this invention as long as the current flows for a long enough time in any one direction to bring about the stable electrochemical condition mentioned so that a measurement can be taken while that condition exists and during the flow of current. If pulsating currents are employed, the pulses should be sufficiently long so that a measurement may be taken during a single pulse, or the intervals between pulses should be sufficiently short to maintain the desired electrochemical condition between pulses.

I claim:

In a method for determining variations in the inclination of strata traversed by a borehole during the drilling thereof, the steps which comprise: operating a drilling apparatus extending within a borehole, to extend the borehole to successively greater depths; passing a unidirectional electric current through the earth between said drilling apparatus, as one electrode, and a fixed electrode connected to the earth at a position removed from the borehole; taking a series of measurements during the flow of said current, indicative of variations in resistance of the path of said current through the earth, as the drilling apparatus is extended to successively greater depths; passing a unidirectional current through the earth between said drilling apparatus, as one electrode, and another fixed electrode connected to the earth at a position removed from the borehole in a different direction than the first-mentioned fixed electrode; and taking a series of measurements during the last-mentioned flow of current, indicative of variations in resistance of the path of said current through the earth, as the drilling apparatus is extended to substantially the same successively greater depths as in the first series of measurements.

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