175-50 CROSS REFERENCE SEARCH ROOM

July 31, 1962 J. BENNETT ETAL 3,047,794

BORE HOLE LOGGING METHODS AND APPARATUS

Filed Sept. 23, 1957 3 Sheets-Sheet 1

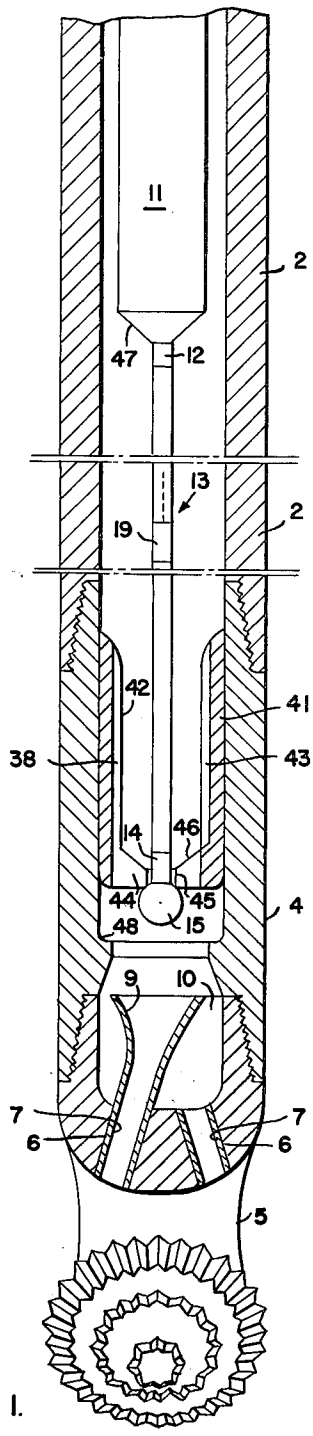


FIG. 1.

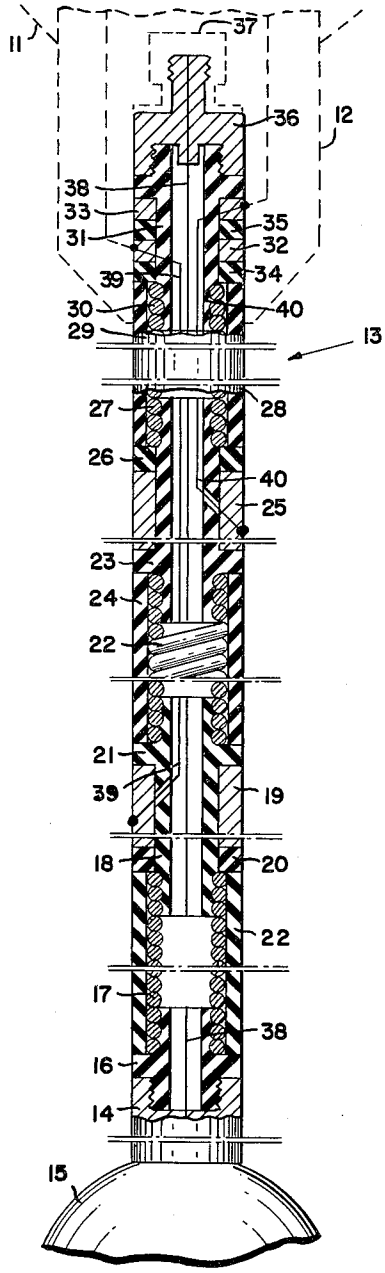


FIG. 2.

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BORE HOLE LOGGING METHODS AND APPARATUS

Filed Sept. 23, 1957 3 Sheets-Sheet 2

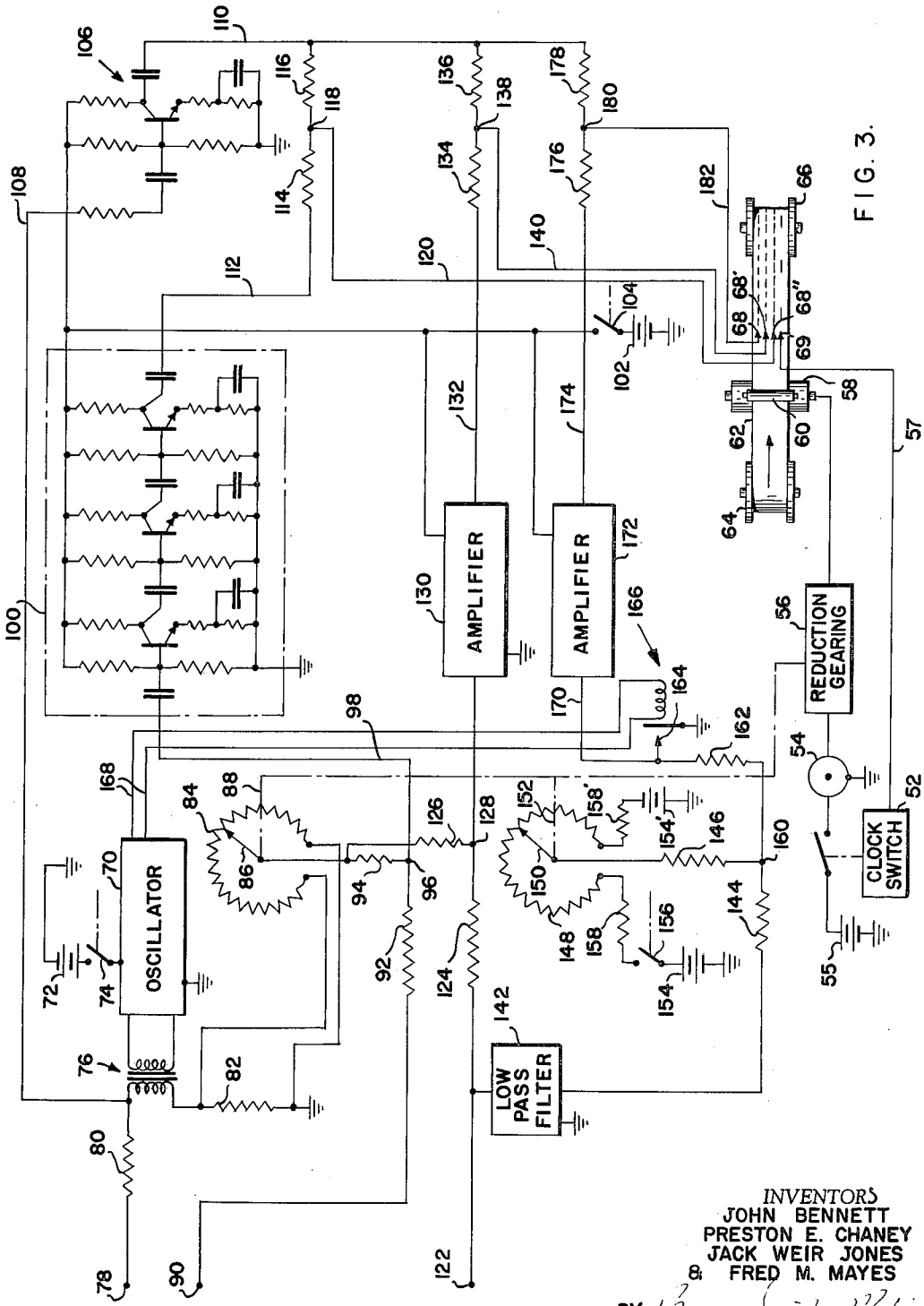


FIG. 3.

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BORE HOLE LOGGING METHODS AND APPARATUS

Filed Sept. 23, 1957 3 Sheets-Sheet 3

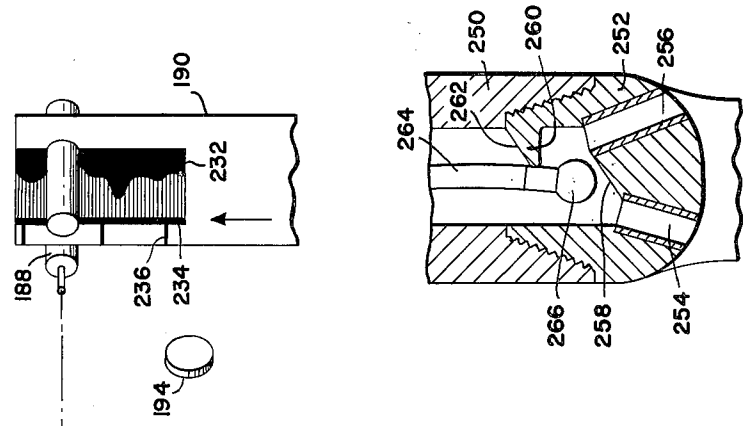


FIG. 5.

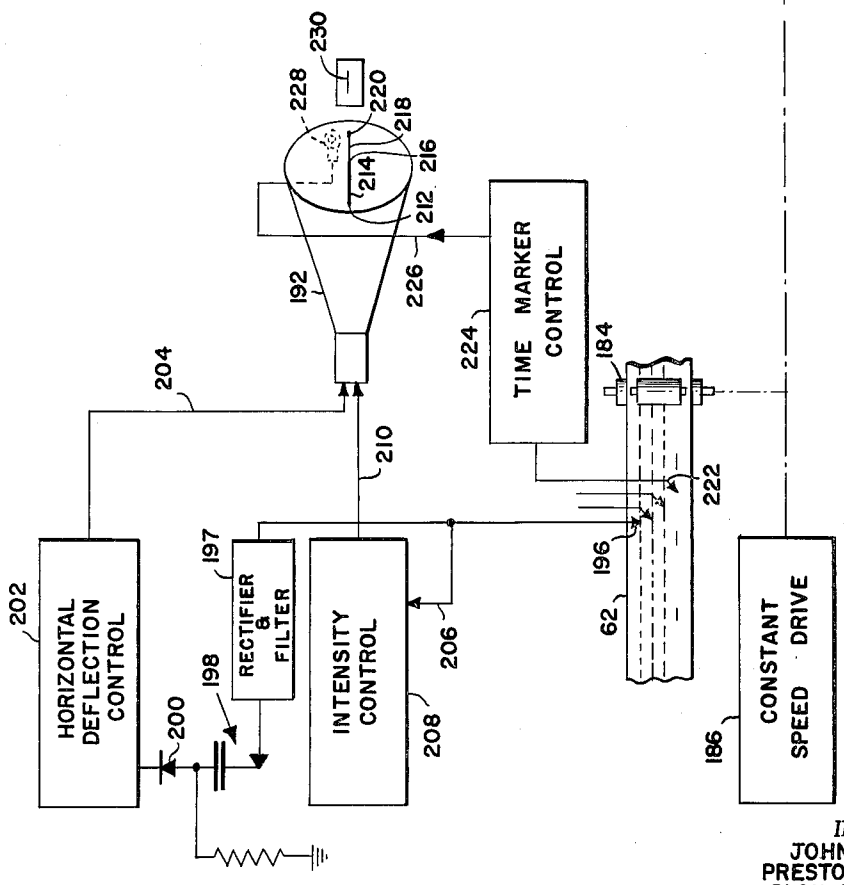


FIG. 4.

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United States Patent Office

3,047,794

Patented July 31, 1962

3,047,794

BORE HOLE LOGGING METHODS AND APPARATUS

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Filed Sept. 23, 1957, Ser. No. 685,717
21 Claims. (Cl. 324—10)

This invention relates to bore hole logging methods and apparatus and particularly to methods which involve the location of recording apparatus within a hole.

Conventional methods of well logging, whether of electrical or other types, involve the absence of the drill stem during the logging operation. This has two serious drawbacks in that not only must special time be consumed in running the well log, during which time the drill stem must be out of the hole, but after a period of drilling due to the fact that the drill stem must be removed, there is inevitably a delay before the new part of the hole may be logged, during which delay there occurs invasion of the formation by drilling liquid. Since the drilling liquid has physical properties of its own, it may, by penetration of porous layers, greatly change their properties so as to interfere with their detection. For example, in the case of electrical logging, the conductivity of the liquid will effect changes in the apparent conductivity of the formations; and in the case of acoustic logging the absorption and velocity of sound will be changed, etc.

Proposals have been made to effect electrical logging by using the drill bit or one or more other parts of the drill stem as logging electrodes. In line with this it has been proposed to supply special drill stem tubing containing one or more conductors which are electrically connected in the assembly of the drill stem and extend to recording apparatus at the surface. The use of such an arrangement has been found to be impractical because of high cost and wear.

Proposals have also been made to support one or more electrodes on wire lines to be dropped below a core bit into the lower portion of a hole from which the bit has been raised. This procedure has also proved impractical inasmuch as special handling has been required at the surface, but particularly because core bits are not generally desired for the major drilling activities but are used only for special purposes.

One of the objects of the present invention is to provide logging methods and apparatus which may be used when a drill string is in a bore hole and may be used at any time with a minimum of interruption in drilling. Not only may the logging be accomplished just prior to removal of the drill string for the purpose of changing a bit, but the logging may be carried out to be promptly followed by a continuation of drilling. In brief, in accordance with this aspect of the invention, a self-contained energizing and recording apparatus may be dropped through a drill string in go-devil fashion or may be pumped down therethrough when the drill string has been lifted to only a limited extent from the bottom of the hole to provide a region for reception of an electrode or other logging assembly. The apparatus in accordance with the invention includes an assembly of a type suitable to pass through the mud flow openings of a jet bit which may be of any of the conventional popular types. Such bits are presently widely used since they effect the carrying away of cuttings and avoid their reworking by the drill. These jet openings are generally at relatively small angles with respect to the drill stem axis and a flexible assembly may, accordingly, be projected therethrough to extend beneath the bit. For electrical logging the assembly is an electrode

assembly; for acoustic or other logging it may be of suitable type for exposure to the walls of a hole.

The self-contained assembly which is lowered to the vicinity of the bit contains, for electrical logging, not only means for supplying current to the earth, but also means for recording various potentials at the electrodes of the assembly. In accordance with the invention the recording is effected, desirably, magnetically.

Recording in a self-contained instrument within a drill stem or bore hole has always presented substantial difficulties because of the limited diametral space afforded. Without the possibility of reference to some standard frequency supply line, there is difficulty in providing constant speed of transport of the recording medium. Furthermore, since the apparatus used must be kept to a minimum, stability of measuring circuits is difficult to maintain.

It is, accordingly, another object of the present invention to provide exciting and recording apparatus which may be self-contained and is sufficiently simple in construction to be housed in apparatus which may pass through a drill stem. In accordance with this aspect of the invention, a pulse width modulation recording system is used which, as will appear hereafter, is essentially independent of supply voltage changes and of the transport speed of the recording medium.

Also avoided in accordance with the present invention is the difficulty of maintaining constant current to the current electrode or electrodes. In the novel system the record depends on the ratio of potentials to the current introduced into the earth.

The foregoing general objects of the invention, as well as other objects relating particularly to details of construction and operation, will be apparent from the following description, read in conjunction with the accompanying drawings, in which:

FIGURE 1 is a sectional view illustrating the lower end of a drill stem, including a jet bit, and the logging assembly in its approach to the position of the bit;

FIGURE 2 is a view, partly in section, showing a typical electrode assembly which may be used;

FIGURE 3 is a diagram, both mechanical and electrical, of the logging apparatus;

FIGURE 4 is a diagram illustrating a suitable reproducing means for a record produced by said apparatus; and

FIGURE 5 is a sectional view similar to FIGURE 1 but showing an alternative arrangement for directing a logging wand through an opening in a jet or other bit having a non-central mud passage.

Referring first to FIGURE 1, there is indicated at 2 the lower end of a drill stem which may be considered to be located in the newly drilled portion of a hole, the drill stem having attached to it through the drill collar 4 a jet bit 5 which is illustrated as of the multiple cone rock type though it will be evident that in accordance with the invention any desired type of bit may be used providing that it has either jet passages or a central passage of the type involved in core bits. Under the conditions existing prior to the beginning of logging, the drill stem will have been raised to an extent to permit an electrode assembly to project below the bit free of engagement with the bottom of the hole.

The bit 5 is provided with the usual jet openings 6 which are usually lined by abrasion-resistant tubes 7. For present purposes, the lining of one of the holes is provided by a tube 8 which extends upwardly to open at 9 in the fashion of a funnel for the reception of the electrode assembly. During the progress of drilling, the mud passes through the tube 8 and through the other openings lined with the tubes 7, reaching the latter through the annular clearance 10 which is of such cross-section as to provide

the proper and approximately equal distribution of mud to the jet holes. Generally the total number of jet holes is equal to the number of cones of a cone type rock bit, there are two such openings in the case of a fish-tail bit, etc. The logging assembly is indicated at 11, and comprises a protective casing capable of withstanding the mud pressures which may be encountered at the bottom of a hole. This casing may be of the same general type as is conventionally used for well surveying instruments. If it is not to be recovered except upon removal of the drill stem, its upper end requires no special structure. If it is to be retrieved from the drill stem prior to the raising of the latter, it may be provided with a conventional spear-head adapted to be engaged by an overshot lowered on a wire line. If it is not to be dropped in go-devil fashion or pumped down through the drill stem, it may be supported by a wire line, whereby it may be lowered through the drill stem when drilling stops and whereby it may be retrieved after a logging operation. Electrically, the casing 11 becomes grounded to the drill stem and provides the ground for its enclosed circuitry.

In accordance with the present invention, the protective casing has extending downwardly from its lower end, supported by an adapter 12, an electrode assembly 13 which will be hereafter referred to as a wand, inasmuch as it is, as a rule, flexible though with sufficient rigidity so that it may be forced downwardly along the wall of a hole without buckling so as finally to extend substantially parallel to the axis of the hole. Depending upon the particular electrode configuration which is desired, the wand may be either relatively short or quite long, being in the latter case upwards of twenty feet in length.

The wand construction is illustrated in detail in FIGURE 2 in which portions which may be of great length are shown broken, the breaks also indicating in some cases repetitions of sections as will be apparent hereafter. It comprises a nose portion 14 which is of metal and constitutes an electrode, which electrode, depending on the electrical configuration used, may be either a current electrode or a potential electrode. Consistent with the use of the wand in the fashion illustrated in FIGURE 1, the nose has secured thereto a ball 15 which may be of rubber or other suitable abrasion-resisting material. Threaded into the nose 14 is a tubular insulator 16 which is provided with a threaded stem to which is secured the lower end of a tightly wound helical spring 17. Such a spring provides high resistance to direct end thrust, but at the same time provides sufficient flexibility for bending of the wand as it passes through a jet opening or must thereafter deflect to extend downwardly along the wall of a bore hole. As will become evident a series of springs such as 17 provide the major body of the wand, there being interspersed insulated electrodes. The upper end of the spring 17 is threaded to the lower end of a tubular insulator 18 on which is mounted a metallic electrode tube 19, the tube being confined between an insulating washer 20 and a flange 21 forming part of the tube 18. The spring 17 which connects the insulating members 16 and 18 is covered by a flexible insulating tube 22 which may be of rubber or flexible plastic. The type of construction just described is then essentially repeated, there being threaded to the upper end of member 18 another spring 22 which is threaded at its upper end to a further tubular insulator 23, the spring being covered by the flexible insulating tube 24 of rubber or plastic. The tube 23 supports between its flange and a washer 26 another tubular electrode 25. In further continuation upwardly, there is another spring 27 surrounded by a flexible insulating covering 28. The construction may be repeated to provide as many electrodes as desired in the required positions thereof. Finally the assembly is terminated by the arrangement involving the spring 30 (which may be the same as spring 27 or different) covered by the insulating tube 29. The upper end of spring 30 is threaded to the insulating tube 31 on which there

are mounted a suitable number of collector rings such as 32 and 33 insulated from each other by insulating washers such as 34 and 35. To the top of the member 31 there is threaded the metallic member 36 which is arranged to be secured as indicated at 37 in a lug contained within the adapter 12. An insulated wire 38 connects the member 36 to the nose electrode 14, while insulated wires such as 39 and 40 connect the individual collector rings to the electrodes such as 19 and 25.

The electrodes may be of lead or other suitable metal, depending upon the particular electrical system employed. In the case of an electrode employed for pickup of self-potential, the electrode may desirably be of the same metal as the drill stem furnishing a reference so as to minimize any direct potential differences due to the use of different materials.

It will be evident from the foregoing that there is provided an assembly which, except for the limited regions at the electrodes, is flexible and yet has sufficient stiffness and resistance to compression so that friction may be overcome during lowering in the bore hole to the end that the wand will extend along the hole and not tend to buckle upon itself. Any desired number of electrodes flush with the outer surface of the wand may be provided and located where desired for the particular configuration involved. It may be noted that the electrodes shown, though they are individually inflexible, are of such short lengths that, from the standpoint of the sinuous path that the wand may be required to follow through a jet bit passage and then along the wall of a hole, the wand as a whole is flexible, though stiff. Other sufficiently short sections of the wand may be inflexible, if desired, with only short flexible joint portions between them. The wand, nevertheless, will, as a whole, be resistant to buckling so that it will extend generally lengthwise of a hole.

Surrounding the lower end of the wand as it is lowered with the casing 11, there is a sleeve member 41 of metal provided with a socket opening 42 for the reception of the lower end of the casing 11. Restricted mud passage grooves 43 are provided in the inner surface of member 41 and communicate with restricted passages 44 at the bottom thereof. This bottom is provided with an opening 45 through which the wand may slide, the wand initially supporting the member 41 by reason of the enlargement provided by the ball 15. One of the functions of the member 41 is to serve as a weight and guide to maintain the wand 13 in substantially axial relationship with the drill stem during lowering. Another is to provide shock absorption to prevent damage to apparatus contained within housing 11. The member 41 is provided with a conical seat 46 arranged to be engaged by the conical lower end 47 of the casing 11. An annular ledge 48 within the drill collar 4 is arranged to arrest downward movement of the member 41.

As the assembly comprising the casing 11, the wand 13 and the member 41 is lowered through the drill stem either by being dropped in go-devil fashion, by being pumped downwardly therethrough by the mud, or by being lowered on a wire line, the member 41 ultimately engages and is arrested by the annular seat 48. Once this occurs, mud flow is restricted by confinement of flow to openings 44 which provide a cross-section substantially less than that provided by the bit openings. Thus a shock absorbing action results. The lower end of the wand is centrallized by the member 41 so that in its continued downward movement the ball 15 enters the funnel portion 9 of the liner 8 to guide the ball and then the wand therethrough, the wand flexing laterally for this passage and then again flexing when it encounters the wall of the bore hole, whereupon it thereafter will move downwardly in contact with the wall. The opening through the liner 8 is directed, as is usual, between the cones of the bit so that free downward passage of the wand may occur. Finally, the lower end of the casing

11 enters the opening 42 of member 41 and seating takes place at 46. The fact that seating has finally occurred will be signalled to the surface by the fact that the pump pressure gauge will show a partial obstruction to free mud flow as the casing 11 enters the seated member 41. Flow of mud is not completely arrested since restricted flow may still continue through the grooves 43. When seating has been accomplished, the wand, and the electrodes thereon, will occupy particular definite positions with respect to the bit, so that their positions within the bore hole will be known. Thereafter logging is effected by the raising of the drill stem with notation of the times at which the drill stem occupies various positions. The upward motion of the drill stem during logging may be uniform or intermittent, depending upon the length of the hole which is to be logged. If the length to be logged in a single operation is less than the free movement of the drill stem within the derrick without involving removal of sections, the logging may be continuous at a substantially uniform rate. If a greater length is to be logged, involving removal of drill stem sections, there will be interruptions of movement of the electrodes during the removal of successive sections. A depth-time record will, in any event, be made, so that the ultimate log may be correlated with depth through time as will appear more fully hereafter.

The invention is not specifically limited to any particular type of logging. The logging may be of electrical type, and this will be more specifically referred to as an example of the application of the invention. However, as will become apparent, the logging may be of other types. It may, for example, be high frequency logging, in which case the wand may carry a radiating coil or may provide spaced coupling capacitances. Radioactive logging may be effected, in which case the wand may contain radiation detecting means. Acoustic logging may also be carried out, in which case the wand may contain either pick up devices only or both pick up devices and means for producing acoustic signals. In any case, the wand is flexible so as to be capable of lateral diversion to pass through jet openings in a bit. As will more clearly appear hereafter, electrical signals, irrespective of the type of logging used, may be magnetically recorded in accordance with the invention.

Since the invention is particularly designed for electrical logging, this will be described in greater detail, and the recording apparatus will be particularly related thereto.

In the case of electrical logging, any of the many known electrode arrangements and systems may be used. For the so-called resistivity logs, these systems involve, in common, an arrangement for producing alternating current flow in the vicinity of the bore hole between one pair of electrodes and other electrodes for picking up potentials. In some cases these electrodes may all be independent. In other cases common electrodes may be used for performing different functions. When self-potential logs are also to be made, the potential may be picked up between electrodes which also function as resistivity electrodes. As will become apparent hereafter, the present invention is broadly applicable to all of the ordinary systems as well as to others which are known but not generally used. For purposes of explanation, there will be now described a specific type of apparatus used in conjunction with a specific system in which current is introduced into the earth between one electrode (the lowermost of the wand electrodes) and the drill stem, the latter functioning as an electrode, with the picking up of a pair of resistivity potentials, one between the drill stem and an electrode located above but in the vicinity of the current electrode, and the other between the drill stem and a still higher electrode considerably spaced from the current electrode. The electrodes should be located remote from the lower end of the drill stem when measuremeants are being made, and consequently the length of wand between the uppermost electrode and its upper end may be many feet, e.g., 20 feet or upward. Self-potential in this system is picked up between either of the resistivity electrodes just mentioned and the drill stem; in fact, the self-potential may be picked up between the current electrode and the drill stem. Thus the drill stem functions as a reference for all three potentials and also as a current electrode. The recording apparatus associated with this system may with minor and obvious changes be applied to other systems in which there may be more individual separations of electrode functions. It may be remarked that due to the conductive extent of the drill stem the resistance between the drill stem and the earth may be regarded as negligible. As a particular special arrangement to which the invention is also obviously applicable, reference may be made to that involving a relatively large number of electrodes to "beam" currents into the formations with the objective of securing indications of particularly thin strata.

Reference may now be made particularly to FIGURE 3, which, except for the showing of electrodes carried by the wand, illustrates apparatus which is located within the casing 11, this apparatus being self-contained without connection to or control from the surface.

Power is supplied by one or more batteries. The electrical apparatus may involve tubes or solely transistors, and the nature of the power supply will depend on the apparatus used, being solely low voltage in the case of apparatus which is of transistor type, or involving high voltage supply, either by way of high voltage batteries or by a vibrator type high voltage power supply in the event vacuum tubes or thyratrons are used. In order to conserve power and also delay operation of the recording mechanism until recording is desired, all or appropriate parts of the output of the power supply or supplies may be controlled by a switch 52 which in FIGURE 3 is designated a clock switch. What is here indicated is the switch which supplies operating power only after the passage of a desired interval of time. The clock switch may be set at the surface to provide a delay in the application of power for such period as is necessary to close the casing 11, lower it to its final position, and initiate the logging operations. Following such preset interval, the switch will apply the power necessary for operation of the other parts of the apparatus. This type of expedient is commonly used in delaying the operation of well surveying instruments. Alternatively, there may be provided a switch which is responsive either to rotation of the drill stem or some other inertial action, for example, as described in the patent to Emerson et al., 2,412,976, dated December 24, 1946. It may be noted that in any case, the initiation of operation may be determined as to time, either by reason of the pre-setting of the clock switch or by the occurrence of some operation such as rotation imparted to the drill stem after the apparatus has been lowered to operating position. The clock mechanism driving the switch may also supply timing markings on a recording tape for depth correlation purposes, as hereafter described.

A motor 54 is driven by the power supply battery 55 through the switch 52. This motor drives through reduction gearing 56 the capstan drum 58 of a magnetic recorder of multi-channel type, the tape 62 of the recorder being pressed against the capstan 58 by means of a rubber pressure roller 60 so as to be, as nearly as possible, advanced at the same speed as the capstan. The tape is supplied from a reel 64 and received by a takeup reel 66. This latter may be driven through the reduction gearing with suitable conventional provisions for slippage. A group of recording heads 68, 68′ and 68″ are indicated, there being more or less of these for recording on a corresponding number of channels depending upon the type of record which is required for the electrode arrangement used. If the motor 54 is of constant speed type, it will be unnecessary to provide additional timing markings on the tape. If, however, the speed may

be expected to be variable to a considerable degree, timing markings may be applied in conventional fashion either from the same clock that drives the switch 52 (as through connection 57 to head 69) or from another clock. The motor 54 may, of course, have its speed monitored and controlled by a clock. It may be pointed out that in the case of the present disclosure the matter of time markings or constant speed is related only to the problem of correlating the log with depth rather than to the accuracy of the recorded resistivity or self potential.

Provided at 70 is an oscillator of any conventional type having any suitable frequency for the particular dimensions of the system employed, for example, a frequency of 100 or more cycles per second. This oscillator is powered by a battery 72 through a switch 74 controlled by the clock switch mechanism 52. The output of the oscillator is delivered through a transformer 76 the secondary of which is connected through resistors 80 and 82 between the uppermost current electrode 78 and the drill stem which is indicated as ground. As before noted in the system described the drill stem, forms the common ground for all references in the circuit. The resistors 80 and 82 are chosen to provide the desired current flow in the formation. As will become apparent, constancy of this current is not of importance, though it may be desirable to maintain it reasonably constant by utilizing resistors of resistance value substantially in excess of that resistance which appears at any time between electrode 78 and ground.

Shunted across the resistor 82 is the resistance 84 of a potentiometer, which resistance is arranged circularly with a short break between its terminals and is wiped by a contact or wiper 86 driven as indicated at 88 from the motor 54 through the reduction gearing 56. For a complete revolution of the contact 86 the recording tape 62 may be advanced a suitable small distance which is dependent on the accuracy of reading desired. For example, the advance per revolution of the wiper 86 may be of the order of one-quarter inch. There may be several revolutions of this wiper per second. At any rate it is desirable that the oscillator 70 should operate at a frequency considerably higher than the frequency of rotation of the wiper, for example, at a frequency upwards of 100 cycles per second as indicated previously. It will be noted that the connections are such that when the potential at terminal 78 is positive with respect to ground the potential of the wiper 86 is negative, and vice versa. The potential at the uppermost potential terminal 90 is, therefore, always opposite in phase to the potential of the wiper. The potentials appearing at electrode 90 and at the wiper are added through resistors 92 and 94 to provide their sum at the terminal 96. It will be evident, therefore, that as the wiper 86 revolves, for example, from the grounded terminal of potentiometer 84 to that terminal connected to the ungrounded end of resistor 82, there will be, when the resistors are properly chosen, a particular position of the wiper 86 at which the potential of terminal 96 will be zero, for any particular ratio between the potential at electrode 90 and the current flowing through electrode 78. Since the electrical configuration of the earth may be properly regarded as linear, for any particular configuration in the region of logging there will be a definite ratio between the potentials appearing at electrode 90 and across the resistor 82, the latter potential being proportional to the current flowing through electrode 78. Thus, the phase angle of wiper 86 in its cycle at which a zero potential output appears at terminal 96 is directly related to the resistivity conditions in the earth existing at that time independent of the current flow through terminal 78 which may vary due to resistance appearing at this terminal, oscillator output variations, or the like. (References at the present time are, of course, to alternating potentials at the oscillator frequency, since as will immediately appear, direct potentials and potentials at other stray frequencies are effectively eliminated.

The potential appearing at terminal 96 provides an input through connection 98 to a high gain amplifier 100. This amplifier, as shown, is conventional and may comprise three transistor stages involving NPN silicon transistors, silicon transistors being preferable in view of their being able to withstand the elevated temperatures which may be encountered in a hole. Signal magnitudes are desirably chosen so that the amplifier 100 has its output limited by overloading. This means that except at the phase position of wiper 86 in the vicinity of zero potential output at terminal 96 the output consists essentially of amplitude limited waves at the frequency of oscillator 70 which change 180° in phase from one side of the zero input to the other. Operation in this fashion leads to simplicity in recording through the use of a phase comparison arrangement involving another amplifier 106 which may consist of a single transistor stage. The input to this amplifier is through connection 108 from one terminal of the secondary of transformer 76. This input is, of course, in phase with the input to the earth from the same terminal of the transformer. Here also because of the high level of signal input, the output from the amplifier 106 is also limited by overloading so that its output delivered at 110 consists of essentially rectangular pulses which on opposite sides of the zero potential condition at terminal 96 are in phase or 180° out of phase with respect to the output at 112 from amplifier 100. By reason of the common power supply from battery 102 through clock operated switch 104, the outputs of the two amplifiers will have at least approximately the same magnitudes. Accordingly, when the outputs at 112 and 110 are respectively added through resistors 114 and 116, there is produced at terminal 118 an output which is very small on one side of the zero condition at terminal 96 and very large on the other side of that condition. The terminal 118 is connected at 120 to the recording head 68". As a result of the foregoing, therefore, during each cycle of revolution of wiper 86 there is produced a cycle of the record consisting in one part of substantially zero signal and in the other part of a high intensity signal at the oscillator frequency. Considering the train of oscillations as a pulse, it will be evident that in each complete cycle on the tape there will appear a pulse the width of which, with respect to the duration of the cycle, is a direct measure of the ratio of potential at electrode 90 to the current through electrode 78, or the reciprocal, depending upon the particular reversals of phase which may have occurred in the particular system employed. The pulse width, with respect to the length of the cycle, is, therefore, a direct measure of earth's resistivity conditions. The system may be conveniently described as involving pulse width modulation recording, but it is to be understood that this does not imply constant frequency of repetition of the cycles. In fact, one of the advantages of the invention is that constancy of frequency is not important, and accordingly no particular care need be exercised to secure constant speed of the motor 54. On the other hand, by utilizing the motor 54 to drive both the wiper 86 and the tape in the recorder, at rates having a constant ratio, there is substantial constancy of cycle length on the tape, though even this is not necessary in view of the fact that the information of interest resides solely in the ratio of pulse width to width of a cycle for each particular cycle involved.

It may be noted that if the oscillator frequency is controlled so as to be reasonably constant, the pulses recorded on the tape may be used for time measurement without additional time markings, it being desirable in this case not to produce in the low intensity portions of the cycles complete balance of the outputs at 110 and 112 so that each cycle of the oscillator will record though at such widely different levels that the high amplitude pulse trains

constituting the variable length pulses may be readily distinguished in ultimate reproduction of the record.

The production of one record channel has now been fully described, and it will now be obvious how the input appearing at the lowermost potential electrode **122** may be similarly recorded on another channel. The potential appearing at this electrode **122** and the potential of wiper **86** are added through the resistors **124** and **126** to produce at terminal **128** an output similar to that produced at terminal **96** in that through a cycle there will be produced a zero alternating potential condition preceded and followed by outputs 180° related in phase. The terminal **128** feeds an amplifier **130** which may be identical with amplifier **100**. Its output at **132** is added to the output **110** from amplifier **106** through the resistors **134** and **136** to provide at terminal **138** signals similar to those appearing at terminal **118**. Terminal **138** is connected at **140** to the recording head **68'** to provide a second record channel.

Self-potentials are picked up between electrode **122** and ground. To effect recording thereof, signals appearing at electrode **122** pass through the low pass filter **142** which is particularly designed for maximum attenuation at the oscillator frequency. The output of the filter is, accordingly, essentially direct, slowly varying in accordance with the rate of logging involving the encountering of different strata. The output of the filter is added through resistors **144** and **146** to the output provided at the wiper **150** of a circular potentiometer **148** similar to potentiometer **84**, the wiper **150** being driven through connection **152** at the same speed and in the same phase relationship as the wiper **86**. The potentiometer **148** is energized by batteries **154** and **154'**, through the clock controlled switch **156** and resistors **158** and **158'**. The connections are such that during a cycle of rotation of wiper **150** there will appear at terminal **160** for one position of the wiper a zero potential output, the potential at this terminal being respectively positive and negative on opposite sides of this position of the wiper. The varying output thus produced is fed through resistor **162** to the contact point **164** of a chopper **166** which is driven from the oscillator at its frequency through connections **168**. The result is the production at **170** of a signal at the oscillator frequency which shifts 180° in phase as the output at **160** passes through zero. From this point on the signal is handled in precisely the same fashion as the alternating signals previously discussed. Amplification is effected by an amplifier **172** which may be identical with amplifier **100**. Its output at **174** is added through resistors **176** and **178** to the output from amplifier **106** to provide at terminal **180** signals of the same type as those previously discussed appearing at terminals **118** and **138**. The terminal **180** is connected at **182** to the recording head **68** to provide a record channel identical with those already described and serving by pulse width modulation to measure the self-potentials appearing at terminal **122**.

The procedure for logging has already been outlined but may now be briefly repeated in the light of description of the recording system within the housing **11**. Following a cessation of drilling, the apparatus within the housing is prepared for recording and the clock switch **52** controlling the energization circuits is set for a time delay sufficient to permit the logging apparatus to be positioned at the lower end of the drill stem and logging commenced. Time synchronization is noted. The housing **11** may be closed, and the assembly of housing and wand dropped or lowered through the drill stem, the drill stem being lifted sufficiently to permit the wand to project fully as the housing **11** reaches its seated position. Then, when the time is noted for beginning logging, the drill stem may be raised at a suitable rate, correlations being noted between position and time. During this raising of the drill stem the apparatus within the housing **11** operates as already fully described to produce the multiple channel records on the tape **62**. When the logging is completed the apparatus may be recovered in one of the fashions already mentioned, being withdrawn by means of an overshot, or by removal of the entire drill stem if it is desired to change the bit. If the region of logging is less than the possible movement of the drill string within the derrick, the logging apparatus may, of course, have been permanently connected to a wire line through which it is both lowered and withdrawn.

It will be evident that the logging may be carried out so quickly after the cessation of drilling that the drilling fluid will not have had a chance to penetrate substantially into porous formations. Thus logging may be carried out without the masking of results which has heretofore frequently occurred due to the long time involved in removing an entire drill stem and correspondingly delaying the beginning of logging.

It will be evident that the types of channels described for the various signals may be supplied in any number required for a particular electrode arrangement. If focusing electrodes are used, the output signal connections may correspond to those illustrated while the current control means of conventional type may be included in the casing **11**, the current being supplied from the oscillator.

From the foregoing it will be evident that the signals which may be recorded by the system described need not originate as electrode potentials, but so long as the signals are either alternating or direct they may be subject to the same types of operations as have been described to produce pulse width modulated records. The signals may, for example, result from high frequency logging; or they may result from acoustic logging, utilizing a system of conventional type for indicating, in terms of a potential, a time interval. Signals may also be derived as measures of counts from a radioactive detection system. It will thus be evident that the system shown particularly in FIGURE 3 is of quite general applicability to well logging.

Whatever the method of logging involved may be, it is desirably carried out, as above described, by the raising of the drill stem relatively slowly during the logging operation so as to carry upwardly within the hole the wand which carries or mounts the detecting elements such as the electrodes which have been described.

Reproduction and recording of the pulse width modulated magnetic record may be carried out in any of various fashions used for transforming such a record into an amplitude modulated visible record with correlation with time. For example, a magnetic pickup associated with each channel may give rise to pulses at the beginning and end of each pulse of the magnetic record, after detection and filtering to transform the trains of pulses at oscillator frequency into rectangular pulses, to trigger, through an amplifier, a bistable multivibrator respectively to its on and off states, the output from one state being then fed through a limiter and low pass filter to effect averaging and provide an amplitude modulated wave which may be photographically recorded using an oscillograph. One suitable circuit for this purpose is disclosed in the application of Blake and Holtkamp, Serial Number 649,485, filed March 29, 1957.

The foregoing circuit involves averaging of pulses, and would require rather rapid rotations of wipers **86** and **150** consistent with relatively rapid movement of the logging apparatus within the hole in order to effectively detect thin strata. Accordingly, there is illustrated in FIGURE 4 another type of recording system in which, essentially, each cycle of the wipers produces an individual contribution to the record, while at the same time the record is of the conventional type with which interpreters of logs are familiar.

The apparatus of FIGURE 4 comprises a capstan arrangement **184** driven by a constant speed drive **186** to advance the tape **62** past recording heads. FIGURE 4 illustrates the apparatus for reproducing a single channel and it will be understood that it may be duplicated for

reproducing all channels simultaneously with optical or multiple gun cathode ray tube systems being used to produce side by side records on a single photographic strip. The constant speed drive 186 may also be used to advance through a capstan arrangement 188 the photographic film or paper **190** on which the final record is to be produced.

A cathode ray oscillograph tube 192 has its trace area focused by a lens system 194 on the photographic record member **190**. The magnetic pickup 196 is arranged to provide, through a rectifier and filter 197 (to transform the pulse trains to pulses at cycle frequency) and through a differentiating circuit 198 and a diode 200, triggering pulses to a horizontal deflection control 202 which, through connection 204, produces horizontal deflection of the electrode beam in the tube 192. As will be evident from what has been previously discussed, the pulse modulated records have trains of high amplitude pulses interspersed with substantially zero signals or low intensity signals. The horizontal deflection control is desirably so arranged (with a slight time delay unit involved) so that upon the initiation of a high intensity train a signal is introduced to the horizontal deflection control and after a slight predetermined delay this control returns the oscilloscope spot to an initial position to initiate a sweep cycle. The control 202 should be adjustable in conventional fashion to predetermine the time for a sweep to correspond to the cycle interval of the record. As has already been mentioned, using the arrangement shown in FIGURE 3 in which the tape is driven by the same motor as the wipers 86 and 150, even if the motor speed changes a single cycle will have the same length on the tape. Thus a constant speed drive 186 in reproduction results in a very nearly constant frequency of the pulse cycle. The signal from head 196 is also delivered at **206** to the intensity control 208 which through output line **210** controls the intensity of the oscilloscope spot, the intensity on the average then being in correspondence with the tape signal. The result, in accordance with the foregoing, is that during one cycle the trace of the oscilloscope spot will be as indicated, the trace starting at 212 and having high intensity at 214 to the point 216 corresponding to the end of the high level train on the record. Then it may continue at 218 at quite low intensity, again having high intensity at 220 to produce a spot marking the end of the sweep. This spot will result if, as stated, the return to the beginning of the sweep is slightly delayed beyond the beginning of the high intensity signal.

For the purpose of picking up time markers, a reproducing head **222** is provided which operates through an amplifier **224** constituting a time marker control to provide an output at **226** to illuminate a neon or similar lamp **228** which through a slit 230, the image of which is projected on the record member **190**, will provide time markings at **236**.

The record will be as indicated on the member 190, the showing illustrating, of course, what would result after development. The high intensity signals produce the area **232** having a boundary corresponding to conventional resistivity or self-potential traces. At 234 there is provided a line marking the successive locations of the spot **220**. By this line a check is afforded of the constancy of the length of the sweep. If this varies, due account may be taken of the variation, since the recorded information is essentially involved in the ratio of the high intensity signal duration to the entire period of the cycle.

It was mentioned above that timing markings could be derived from the oscillator cycles. This may be readily effected by counting the cycles put out by the head 196 and providing an output, for example, upon each hundredth cycle to provide high intensity of the oscilloscope spot throughout a complete sweep, thereby providing horizontal lines for time indicating.

FIGURE 5 shows an arrangement, alternative to that of FIGURE 1, for insuring passage of a wand through a non-central mud passage of a bit. The drill collar or sub 250 carries the bit 252 which is shown as a multiple cone rock bit but may be of other types such as a fishtail bit having one or more non-central mud passages. The said mud passages are shown at 254 and 256. The wand is to pass through the passage 254, and for this purpose its upper end is flared to provide a guiding cone 258. A ledge 260 having a sloping upper surface 262 is provided to divert the wand 264 in a path which will insure its entrance into the cone 258. A ball 266 may, as in the case of the modification in FIGURE 1, be provided at the lower end of the wand, but this may be omitted, if desired.

The recording apparatus disclosed herein is claimed in the copending application of Fred M. Mayes and Jack Weir Jones, Serial No. 683,027, filed September 10, 1957.

What is claimed is:

1. A method of logging a bore hole after cessation of drilling by the use of a rotary bit carried by a hollow drill stem, the bit being of a type having at least one mud passage extending downwardly and non-concentric with the drill stem axis, which method comprises lowering through the drill stem, after cessation of drilling, logging apparatus including an elongated flexible member carrying a logging element and guiding said member through such mud passage, and to a predetermined position relative to the bit, when the bit is raised from the bottom of the hole, thereby to effect projection of said logging element below the bit, and then progressively moving the drill stem to cause said element to traverse a portion of the hole to effect logging.

2. A method of logging a bore hole after cessation of drilling by the use of a rotary bit carried by a hollow drill stem, the bit being of a type having at least one mud passage extending downwardly and non-concentric with the drill stem axis, which method comprises lowering through the drill stem, after cessation of drilling, logging apparatus including a housing containing log recording means and an elongated flexible member supported thereby and carrying a logging element connected to said log recording means to provide signals thereto, and guiding said member through such mud passage, and to a predetermined position relative to the bit, when the bit is raised from the bottom of the hole, thereby to effect projection of said logging element below the bit, and then progressively moving the drill stem to cause said element to traverse a portion of the hole to effect logging.

3. A method according to claim 1 in which the flexible member carries as said logging element an electrode for electrical logging, and in which current is caused to flow in the earth in the vicinity of said electrode during said traversal with the electrode picking up earth potentials.

4. A method according to claim 2 in which the flexible member carries as said logging element an electrode for electrical logging, and in which current is caused to flow in the earth in the vicinity of said electrode during said traversal with the electrode picking up earth potentials.

5. Apparatus comprising a hollow drill stem carrying at its lower end a drill bit of a type having at least one mud passage extending downwardly and non-concentric with the drill stem axis, logging apparatus arranged to move downwardly through the drill stem and including a housing and an elongated member supported thereby and extending downwardly therefrom, said member carrying a logging element requiring for operation projection below the bit, and means for guiding said member into and through said mud passage to effect said projection, said member having both flexibility and substantial stiffness so that by the action of downward pushing force exerted on its upper end it will be deflected from parallelism with the drill stem axis to pass through said mud passage and extend downwardly in substantially straight condition along the bore hole below the bit.

6. Apparatus comprising a hollow drill stem carrying at its lower end a drill bit of a type having at least one

mud passage extending downwardly and non-concentric with the drill stem axis, logging apparatus arranged to move downwardly through the drill stem and including a housing containing log recording means and an elongated member supported thereby and extending downwardly therefrom, said member carrying a logging element connected to said log recording means to provide signals thereto and requiring for operation projection below the bit, and means for guiding said member into and through said mud passage to effect said projection, said member having both flexibility and substantial stiffness so that by the action of downward pushing force exerted on its upper end it will be deflected from parallelism with the drill stem axis to pass through said mud passage and extend downwardly in substantially straight condition along the bore hole below the bit.

7. Apparatus comprising a hollow drill stem carrying at its lower end a drill bit of a type having at least one mud passage extending downwardly and non-concentric with the drill stem axis, logging apparatus arranged to move downwardly through the drill stem and including a housing and an elongated member supported thereby and extending downwardly therefrom, said member carrying a logging element requiring for operation projection below the bit, and said member having both flexibility and substantial stiffness so that by the action of downward pushing force exerted on its upper end it will be deflected from parallelism with the drill stem axis to pass through said mud passage and extend downwardly in substantially straight condition along the bore hole below the bit.

8. Apparatus comprising a hollow drill stem carrying at its lower end a drill bit of a type having at least one mud passage extending downwardly and non-concentric with the drill stem axis, logging apparatus arranged to move downwardly through the drill stem and including a housing containing log recording means and an elongated member supported thereby and extending downwardly therefrom, said member carrying a logging element connected to said log recording means to provide signals thereto and requiring for operation projection below the bit, and said member having both flexibility and substantial stiffness so that by the action of downward pushing force exerted on its upper end it will be deflected from parallelism with the drill stem axis to pass through said mud passage and extend downwardly in substantially straight condition along the borehole below the bit.

9. Apparatus comprising a hollow drill stem carrying at its lower end a drill bit of a type having at least one mud passage extending downwardly and non-concentric with the drill stem axis, logging apparatus arranged to move downwardly through the drill stem and including an elongated member, said member carrying a logging element requiring for operation projection below the bit, and means for guiding said member into and through said mud passage to effect said projection, said member having both flexibility and substantial stiffness so that by the action of downward pushing force exerted on its upper end it will be deflected from parallelism with the drill stem axis to pass through said mud passage and extend downwardly in substantially straight condition along the bore hole below the bit.

10. Apparatus comprising a hollow drill stem carrying at its lower end a drill bit of a type having at least one mud passage extending downwardly and non-concentric with the drill stem axis, logging apparatus arranged to move downwardly through the drill stem and including an elongated member, said member carrying a logging element requiring for operation projection below the bit, and said member having both flexibility and substantial stiffness so that by the action of downward pushing force exerted on its upper end it will be deflected from parallelism with the drill stem axis to pass through said mud passage and extend downwardly in substantially straight condition along the bore hole below the bit.

11. Apparatus according to claim 5 in which said guiding means comprises a tubular member having an enlarged upper opening for reception of said elongated member and extending from said opening into alignment with said mud passage.

12. Apparatus according to claim 9 in which said guiding means comprises a tubular member having an enlarged upper opening for reception of said elongated member and extending from said opening into alignment with said mud passage.

13. Apparatus comprising a hollow drill stem carrying at its lower end a drill bit of a type having at least one mud passage extending downwardly and non-concentric with the drill stem axis, logging apparatus arranged to move downwardly through the drill stem and including a housing containing log recording means and an elongated member supported thereby and extending downwardly therefrom, said member carrying a logging element connected to said log recording means to provide signals thereto and requiring for operation projection below the bit, and means for deflecting said elongated member and guiding it into and through said mud passage to effect said projection.

14. Logging apparatus adapted to move downwardly through a drill stem comprising a housing and an elongated flexible member carried by and extending below said housing and adapted to pass through an opening in the lower end of a drill stem, said member having such substantial stiffness that it may be advanced in extended condition against resistance encountered at its lower end by forces applied to its trailing end, said flexible member carrying a logging element.

15. Apparatus according to claim 14 in which said logging element is an electrode for electrical logging.

16. Logging apparatus adapted to move downwardly through a drill stem including an elongated flexible member having such substantial stiffness that it may be advanced in extended condition by forces applied to its trailing end, said flexible member carrying a logging element.

17. Apparatus according to claim 16 in which said logging element is an electrode for electrical logging.

18. Apparatus according to claim 14 in which said housing carries log recording apparatus.

19. Apparatus according to claim 15 in which said housing carries log recording apparatus.

20. Apparatus comprising a hollow drill stem carrying at its lower end a drill bit of a type having at least one mud passage extending downwardly and non-concentric with the drill stem axis, logging apparatus arranged to move downwardly through the drill stem and including a housing and an elongated member supported thereby and extending downwardly therefrom, said member carrying a logging element requiring for operation projection below the bit, said member having flexibility such that it may deflect from parallelism with the drill stem axis to pass through said mud passage and extend downwardly in substantially straight condition along a bore hole below the bit, said drill stem containing means for holding the housing in a predetermined position relative to the bit so that logging may be effected by moving the drill stem lengthwise of the bore hole to cause said member to traverse predetermined portions thereof.

21. Apparatus comprising a hollow drill stem carrying at its lower end a drill bit of a type having at least one mud passage extending downwardly and non-concentric with the drill stem axis, logging apparatus arranged to move downwardly through the drill stem and including a housing containing log recording means and an elongated member supported thereby and extending downwardly therefrom, said member carrying a logging element connected to said log recording means to provide

signals thereto and requiring for operation projection below the bit, said member having flexibility such that it may deflect from parallelism with the drill stem axis to pass through said mud passage and extend downwardly in substantially straight condition along a bore hole below the bit, said drill stem containing means for holding the housing in a predetermined position relative to the bit so that logging may be effected by moving the drill stem

lengthwise of the bore hole to cause said member to traverse predetermined portions thereof.

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