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(54) METHODS AND APPARATUS FOR PROCESSING WELL LOGGING DATA

(71) We, SCHLUMBERGER IN-
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 Panama, 19, Berkeley Street, London, W.1.
 England, do hereby declare the invention, for
 which we pray that a patent may be granted
 to us and the method by which it is to be per-
 formed, to be particularly described in and by
 the following statements:—

This invention relates to methods and
 apparatus for investigating earth formations
 traversed by a borehole. More particularly, the
 invention relates to the processing of well
 logging data derived from apparatus lowered
 in a borehole for investigating the subsurface
 earth formations.

In seeking to determine the presence and
 depth of hydrocarbon bearing zones (oil, gas,
 etc.) that may exist in the subsurface earth
 formations adjacent to a borehole drilled into
 the earth, various types of exploring devices
 may be lowered into the borehole for measur-
 ing various properties of the formation adja-
 cent the borehole. The three principle types
 of such exploring devices are electrical explor-
 ing devices (either electrodes or induction
 coils), sonic exploring devices, and radio-
 activity exploring devices (gamma-ray,
 neutron, etc.).

The electrical exploring devices measure the
 electrical resistivities (or conductivities) of the
 earth formations. These electrical resistivities
 are determined primarily by the amount, dis-
 tribution and resistivity of the fluid or fluids
 contained in the formation pore spaces. The
 sonic exploring devices, on the other hand,
 measure the time required for sonic waves to
 travel across a given span of the earth forma-
 tion. This sonic travel time is determined pri-
 marily by the nature of the rock structure and
 particularly its porosity. The radioactivity ex-
 ploring devices measure either the natural
 radioactivity of the formations or the radio-
 activity induced therein by bombardment of
 the formations with radioactivity particles or
 rays.

Two particular radioactivity exploring de-
 vices used to investigate formations are the
 formation density logging tool and the neutron
 logging tool. The formation density logging
 tool emits gamma-rays which are diffused
 through the formation and the number of dif-
 fused gamma-rays reaching one or more near-
 by detectors are counted to provide a measure
 of the electron density of the adjacent forma-
 tion. Moreover, it is known that this electron
 density is very closely proportional to the bulk
 density of the formation in substantially all
 cases. (For cases where this proportionality
 does not apply, appropriate corrections can be
 made).

The neutron tool, on the other hand, utilizes
 a source for emitting neutrons into the adja-
 cent formations. In one form of neutron device,
 these neutrons lose energy by collision with
 atoms in the formation. When the energy level
 of these neutrons is reduced to the epithermal
 energy range, they can be detected by a nearby
 detector, which counts the number of epither-
 mal neutrons. Since hydrogen atoms are the
 only ones whose weights are almost equal to
 that of the neutron, they are the most effective
 in reducing the energy level of the neutrons to
 enable their capture. Thus, it can be said that
 this type of neutron log is essentially a record
 of the hydrogen atom density of the rocks sur-
 rounding the borehole. Since the formation
 pore spaces are generally filled by either water
 or liquid hydrocarbons which have about the
 same amount of hydrogen, the neutron log does
 not distinguish between oil and water, but is
 primarily affected by the formation porosity.

In general, none of these measurements
 taken alone give a direct and positive indica-
 tion as to the presence or amount of hydro-
 carbons in the formations or the relative diffi-
 culty in removing these hydrocarbons. The
 various factors which affect each measurement
 have to be taken into account and an interpre-
 tation or deduction made as to the probable
 existence of hydrocarbons. Among the factors

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which are considered to be important in determining the location, amount, and ease of removal of oil are the porosity and lithology of the formations. Porosity is the fraction of the total volume of a given portion of the formation which is occupied by pores, or void spaces. Lithology, on the other hand, concerns the type of solid material, (i.e., sandstone, limestone, dolomite, etc.) present in the formations.

It is known that by combining the measurements derived from the formation density log, the sonic log, and the neutron log, three independent measurements of certain physical properties of the formations can be obtained. Since the relationships for porosity and lithology for each of these logs are well known, simultaneous solutions of the equations for the three logging tools can be made to provide representations of porosity and lithology. Additionally, since it is known that the sum of all of the lithologic constituents plus porosity must equal one, there are in reality four equations and thus the solution of four unknowns can be obtained from such a four-by-four matrix. By so doing, solutions can be obtained for the percentage of volume of the formations contributed by the various formation parameters, i.e., in this case, the three lithologic constituents and porosity.

However, the accuracy of the above solution depends on the correct choice of the particular formation parameters which are to be used in the simultaneous solutions of the equations. While many times it may be known which parameters are present in the formations, there are many cases where this is not known. In this regard, it would be desirable to be able to accurately select the formation parameters which are to be used in the simultaneous solutions of the four equations. In general, the expression "formation parameters" refers to the various constituents of a formation such as porosity and different minerals such as sandstone, limestone, dolomite, shale, etc.

According to one aspect of the present invention, there is provided a method of producing electrical signals representative of characteristic properties of an earth formation which is traversed by a borehole and is made up of an unknown set of formation parameters, comprising the steps of: deriving electrical measurement signals respectively representative of measurements of plural characteristics of an earth formation at a depth level; combining such measurement signals to produce first electrical signals representative of respective proportions of formation parameters computed for said earth formation on the assumption that said formation is made up of a first predetermined set of formation parameters; testing the feasibility of said first computed proportions represented by said first signals; combining such derived measurement signals to produce second electrical signals representative

of respective proportions of formation parameters computed for said earth formation on the assumption that said formation is made up of a second predetermined set of formation parameters, if said first computed proportions are not feasible; and testing the feasibility of said second computed proportions represented by said second signals, whereby to select said first electrical signals as an indication of the true formation parameters at the depth level if the first computed proportions are feasible and said second electrical signals as such indication if said first computed proportions are not feasible and said second computed proportions are feasible.

According to another aspect of the present invention, there is provided apparatus for processing data representative of an earth formation traversed by a borehole, comprising: means for deriving measurements of a plurality of characteristics of an earth formation; means responsive to said measurements for computing the proportions of formation parameters of said earth formation on the assumption that said formation is made up of a first set of formation parameters and generating output signals representative thereof; means responsive to said output signals for testing the feasibility of said formation parameter proportion computations and generating a feasibility test signal representative thereof; and means responsive to said measurements and said feasibility test signal for computing the proportions of formation parameters of said formation on the assumption that said formation is made up of a second predetermined set of formation parameters if the computations using said first set of formation parameters are not feasible.

For a better understanding of the present invention, together with other and further objects thereof, reference is had to the following description taken in connection with the accompanying drawings, the scope of the invention being pointed out in the appended claims.

Referring to the drawings:

FIGURES 1A and 1B show an investigating apparatus having a plurality of exploring devices for investigating the adjoining earth formations along with a schematic representation of apparatus for processing well logging signals derived from the investigating apparatus in accordance with the present invention;

FIGURE 2 shows data processing circuitry which can be used with the apparatus of Figure 1;

FIGURE 3 shows typical recorded logs that could be expected when using the methods and apparatus of the present invention; and

FIGURES 4A and 4B show a flow diagram of the methods of the present invention for use in programming a general purpose digital computer.

Now referring to Figure 1, there is shown one embodiment of the present invention. To

make a complete picture of Figure 1, Figure 1A is positioned to the left of Figure 1B. Figures 1A and 1B will be collectively referred to as Figure 1, and show an investigating apparatus 10 located in a borehole 11 on the end of an armored multiconductor cable 12 which is raised and lowered in the borehole by suitable drum and winch mechanism (not shown). The investigating apparatus 10 includes a suitable sonic device 13 for measuring the acoustical travel time of the formations. Sonic exploring devices of this type can be found in U.S. Patent No. 2,938,592 granted to C. J. Charske et al on May 31, 1969 and U.S. Patent No. 3,231,041 granted to F. P. Kokesh on January 25, 1966. The downhole investigating apparatus 10 also includes a sidewall epithermal neutron exploring device 14, having a source and detector mounted on a skid 14a, for measuring the hydrogen content of the adjoining formations and thus the porosity of the adjoining formations. Exploring devices of this type can be found in U.S. Patent No. 2,769,918 granted to C. W. Tittle on November 6, 1956 and French Patent No. 1,583,809 granted on 27th October 1969 to Société de Prospection Electrique Schumberger. If desired, a conventional neutron exploring device could be utilized in place of the sidewall epithermal neutron device. In such a neutron tool, neutrons emitted into a formation are captured by certain types of atoms in the formation which results in the emission of very high energy level gamma-rays, called capture gamma-rays. These capture gamma-rays are counted by a nearby detector. This type of neutron tool is also responsive to the hydrogen content of the formation.

The investigating apparatus 10 also includes a formation density exploring device 15 of the gamma-ray type for producing well logging measurements which can be utilized to calculate the bulk density of the adjoining formations. In this regard, a skid 15a houses a source and two detectors spaced different distances from the source. This arrangement of source and detectors produces signals that correspond to the bulk density of the investigated earth formation. The theory, construction and operation of the gamma-ray measuring device 15 are described more completely in "Dual Spacing Formation Density Log" by J. S. Wahl, J.

Tittman, C. W. Johnstone and R. P. Alger, *Journal of Petroleum Technology*, December 1964, pages 1411—1416; "The Physical Foundations of Formation Density Logging (Gamma-Gamma) by J. Tittman and J. S. Wahl, *Geophysics*, April 1965, pages 284—294; "Formation Density Log Applications in Liquid-Filled Holes" by R. P. Alger, L. L. Raymer, Jr., W. R. Hoyle and M. P. Tixier, *Journal of Petroleum Technology*, March 1963, pages 321—332; and U.S. Patent No. 3,321,625 granted on May 23, 1967 to John S. Wahl.

To keep the investigating apparatus 10 centered in the borehole, a pair of extendible wall-engaging members 14b and 15b are provided opposite the pad members 14a and 15a. To keep the upper portion of the investigating apparatus 10 centered, a plurality of spacers 16 are provided. A borehole caliper also is combined with the arms which extend the skids 15a and 15b and supplies a signal representative of borehole diameter to the surface of the earth.

The signals derived from the downhole investigating device are applied to a signal processing circuit 17 which operates to prepare the signals for use by the remainder of the surface processing circuitry, including referencing all of these signals to the same depth level. The signal processing circuits also operate to compute the neutron derived porosity ϕ_N produced by the neutron logging device and the bulk density ρ_B produced in response to certain signals from the formation density logging tool 15. The output signal from circuits 17 are ϕ_N , ρ_B and the acoustic travel time Δt .

It has been the practice in the past for a well logging analyst to utilize the sonic travel time measurement Δt , the neutron derived porosity measurement ϕ_N , and the formation density derived measurement for bulk density ρ_B to solve for a more accurate porosity. Additionally, these measurements have been used to solve for percentages of a limited number of lithological constituents of the adjoining formations. How this can be accomplished can be easily explained by writing the equations for ρ_B , Δt and ϕ_N in terms of the porosity and different lithological constituents. These equations are:

$$k_1 \Delta t = P_1 \Delta t_1 + P_2 \Delta t_2 + P_3 \Delta t_3 + P_4 \Delta t_4 + \dots + \quad (1)$$

$$k_2 \phi_{N(LMS)} = P_1 H_1 + P_2 H_2 + P_3 H_3 + P_4 H_4 + \dots \quad (2)$$

$$k_3 \rho_B = P_1 \rho_1 + P_2 \rho_2 + P_3 \rho_3 + P_4 \rho_4 + \dots \quad (3)$$

Where the symbols P_1 , P_2 , and P_3 represent the percentages of bulk volume of various formation parameters and the corresponding subscripts 1, 2, 3, and 4 correspond to the response of the particular exploring device to

that particular formation parameter, e.g., primary or secondary porosity or a particular mineral. k_1 , k_2 , and k_3 are calibration constants determined by such things as the tool response. The LMS subscript for ϕ_N specifies that the

tool is calibrated to zero response in limestone. Thus, for example, Δt_1 is the sonic response to the No. 1 formation parameter. H_1 is the hydrogen index of the No. 1 parameter, ρ_1 is the density of the No. 1 mineral, etc. All of these factors (Δt_1 , H_2 , ρ_3 , etc.) are expressed for a given geographical location. They may vary by horizons (depth), but are generally always known at the well site before beginning the logging run. The + . . . represents the fact that there are numerous other materials which may be part of Equations (1), (2), and (3). It can also be stated that the sum of all the

percentages of the bulk volume of the formation parameters must equal one. Thus:

$$P_1 + P_2 + P_3 + P_4 + \dots = 1 \quad (4)$$

Thus, it can be seen that there are four equations, and thus the solution to four unknowns can be provided by simultaneously solving Equations (1) through (4). All other formation parameters besides four have to be assumed to be nonexistent in the formation. Thus, rewriting equations (1) through (4) in terms of only four formation parameters:

$$k_1 \Delta t = P_1 \Delta t_1 + P_2 \Delta t_2 + P_3 \Delta t_3 + P_4 \Delta t_4 \quad (5)$$

$$k_2 \phi_{N(LMS)} = P_1 H_1 + P_2 H_2 + P_3 H_3 + P_4 H_4 \quad (6)$$

$$k_3 \rho_B = P_1 \rho_1 + P_2 \rho_2 + P_3 \rho_3 + P_4 \rho_4 \quad (7)$$

$$P_1 + P_2 + P_3 + P_4 = 1 \quad (8)$$

For the solution of this 4 by 4 matrix described by Equations (5) through (8) to be accurate, the four formation parameters represented by the subscripts 1, 2, 3 and 4 must be chosen properly. If a wrong assumption is made as to this, the results may very well be completely inaccurate. One reason for this is that the constants (i.e., Δt_1 , ϕ_N , ρ_3 , etc.) are different for each formation parameter. In addition to the percentage errors, of course, the answer provided by the logging analyst will include a wrong formation parameter.

As will be hereinafter described, a technique has been found that will accurately determine what parameters should be used in Equations (1—4). In accordance with this new technique, a plurality of sets of four formation parameters are arranged in the order of their probable occurrence. Each of these sets of four formation parameters is called a "matrix set". Starting with the first most probable matrix set, the percentage of each parameter of the matrix set is computed and tested for feasibility. If the solution to the first most probable matrix set appears to be reasonable, the bulk volume percentage of each formation parameter is read out for recording. If, on the other hand, the answers provided by the first most probable matrix set appear improbable, the second most probable matrix set is chosen and the matrix is solved for the percentage of each parameter of the second matrix set. The answers provided by the second matrix set are then checked for feasibility and if feasible, are read out for recording. If they do not appear feasible, the third most probable matrix set is selected. This procedure continues until answers which appear to be feasible are found.

Since there are so many different parameters which can be found in earth formations, such as different types of minerals porosity and

fluid, information derived from logging tools other than those which produce the input data to the matrix sets, i.e., Δt , ϕ_N , and ρ_B , are used as an aid in determining which matrix sets are most probable. Thus, for example, the spontaneous potential, natural radioactivity, or anything else can be measured at each depth level as an aid in determining which matrix sets are most probable. Taking a specific example of this, if the spontaneous potential is greater than a given critical value, it is likely that the formation is a porous and permeable sand. On the other hand, if the measured spontaneous potential is below a given critical value, it is reasonably certain that the formation is a shale formation. As a further example, if there is no measured spontaneous potential, then it has been found that water-filled porosity values in excess of a given critical value, e.g., 8%, are unlikely and it can therefore be reasonably assumed that the wrong matrix set has been selected if such high porosity values are computed.

Referring back to Figure 1, the well logging measurements Δt , ϕ_N , ρ_B from signal processing circuit 17 are applied to matrix computers 1 through n by way of a plurality of gates 19—26. To energize these gates 19—26, a counter 27 is energized by clock pulses generated by a clock or oscillator 38. The clock pulses pass through a gate 37 upon depth pulses from a depth pulse generator 28 setting a flip-flop 36. The depth pulse generator 28 includes a rotating wheel 29 which is in engagement with the cable 12 whereby the depth pulse generator 28 will generate a depth pulse for each given increment of travel of the cable 12.

The clock pulses from clock 38 and gate 37 are counted by the counter 27 so that the counter will sequentially produce output signals on the output terminals designated, 1—n.

These output signals are utilized to energize the gates 19—26 in sequence so that the well logging measurement signals Δt , ϕ_N and ρ_B will be sequentially applied to each matrix computer in sequence. The matrix computers 1—n solve for the percentage that each formation parameter of the particular matrix set contributes to the total bulk volume of the formations. The four output signals from each matrix computer are applied to a combining circuit 30 for application to a buffer memory 48 via parallel gates 49. The gates 49 are energized by a "gate enable pulse" and, when energized, apply signals to the buffer memory 48 which stores them for application to a recorder 31. Each channel of the memory 48 stores an applied signal until updated by a new signal from one of the matrix computers via gates 49. The recorder 31 is driven by a shaft 32 rotated by a rotating wheel 33 in engagement with the cable 12 so that the stored signals in buffer memory 48 will be recorded by recorder 31 as a function of borehole depth. Since only one matrix computer at a time can be producing output signals due to the action of the gates 19—26 and counter 27, the combining circuit 30 connects the similarly designated output terminals of each matrix computer together so that only four signals at a time will be applied to buffer memory 48. That is, the parameter No. 1 (P_1) output terminal from each matrix computer is connected together, etc. If desired, the combining circuit 30 can also provide suitable isolation between the outputs of each matrix computer.

The output signals from the matrix computers 1—n are also applied to a plurality of feasibility test circuits, numbered 1 through n respectively to correspond with the matrix computer designations. These feasibility test circuits operate to check the answers provided by each individual matrix computer and determine whether they are feasible. If the answers are feasible, the particular feasibility test circuit corresponding to the matrix computer whose output signals are under test, generates an output signal via an OR gate 35 and diode 35a which resets the counter 27 to zero and resets the flip-flop 36. Since the well logging measurements Δt , ϕ_N , and ρ_B are applied to each matrix computer in sequence, the computed answers produced by each matrix computer will also be sequentially supplied to the corresponding feasibility test circuits.

Since the counter 27 and flip-flop 36 are reset whenever the answers provided by one of the matrix computers are feasible, it can be seen that the system, starting with the most probable matrix set, will compute the percentage of bulk volume of the formation para-

meters for each matrix set in sequence until feasible answers are obtained at which time the entire system is reset in readiness for the next depth pulse from the depth pulse generator 28.

The output signals from each of the feasibility test circuits 1 through n are also applied to a plurality of parallel voltage generators 40 which each operate to generate a voltage having an amplitude which is unique to each of the matrix sets 1—n. Thus, for example, an output signal from the feasibility test circuit No. 1 could cause a signal of 1 volt to be generated, the feasibility test circuit No. 2 could cause 2 volts to be generated, etc. The output conductors from the parallel voltage generator 40 are applied to a suitable combining circuit 41 for application to the recorder 31. By this arrangement, a signal having an amplitude representative of which matrix set has been selected by the system will be used or recorded by the recorder 31.

As stated earlier it may be desirable to utilize information from various logging tools as an aid in determining which matrix set is applicable to any given formation depth level. For example, spontaneous potential measurements, gamma-ray measurements, resistivity measurements, etc., could be utilized as an aid in determining which matrix set is to be selected. In Figure 1, as an example, the spontaneous potential measurement is utilized as an aid in determining which matrix set is to be selected. To this end, the signal processing circuits 17 produce a spontaneous potential measurement, designated SP, which is applied to a voltage discriminator 45. The discriminator 45 determines if the SP voltage is equal to or less than a selected critical or cut-off value. If the SP measurement is equal to or less than this critical SP value, a signal is generated from the discriminator 45 and applied via an AND gate 46 to the counter 27 to set it to a desired advanced state. The other input to the AND gate 46 is derived from the depth pulse generator 28 so that the counter 27 can only be set to the advanced state at the initiation of each sequence of operation of the system and not in the middle of a sequence of operation. (A sequence of operation is defined as the entire operation by the Figure 1 system between consecutive depth pulses, i.e., the entire operation at one depth level).

As an aid in understanding how the system of Figure 1 operates, it would be desirable to consider specific examples of commonly found matrix sets. Thus, referring to Table I below, there is shown the formation parameters which make up each of the matrix sets 1—n.

TABLE I

Matrix	Parameter 4	Parameter 3	Parameter 2	Parameter 1
1	Laminated Shale	Volcanic	Quartz	Water-filled Porosity
2	Laminated Shale	Dispersed Clay	Quartz	Water-filled Porosity
3	Quartz	Volcanic	Gas-filled Porosity	Water-filled Porosity
4	Laminated Shale	Volcanic	Coal	Water-filled Porosity
5	Laminated Shale	Volcanic	Quartz	Water-filled Porosity
6	Laminated Shale	Volcanic	Coal	Water-filled Porosity
7	Laminated Shale	Dispersed Clay	Quartz	Water-filled Porosity
n	Laminated Shale	Dispersed Clay	Coal	Quartz

The first four matrix sets correspond to porous and permeable sands which are usually indicated when the SP amplitude is above a given critical or cut-off value. The matrix sets 5, 6, 7 and n correspond to shaly formations which are usually indicated when the SP is below this cut-off value.

Now concerning the operation of the system of Figure 1 when utilizing the example of Table I, the SP discriminator 45 checks to determine if the SP voltage is equal to or less than the critical voltage SP_c . Assuming that the SP voltage is greater than SP_c , the AND gate 46 will remain disabled and the depth pulse from depth pulse generator 28 will not pass to counter 27. The depth pulse will however set the flip-flop 36 so as to open the gate 37 and allow clock pulses from the clock 38 to advance the counter 27. Since the counter 27 had been previously reset to its zero state, the first clock pulse will advance the counter to its 1 state thus energizing the gates 19 and passing the well logging measurements Δt , ϕ_N and ρ_N to the matrix computer No. 1. Matrix computer No. 1 computes the percentages of each parameter in accordance with Equations (5-8) and generates four output signals representative of these percentages.

From Table I, it can be seen that parameters 2-4 are minerals. Since there cannot be a negative percentage of any mineral, the parameter 2-4 output signals from matrix computer No. 1 are tested for negative polarity.

Furthermore, the percentage of the formation volume comprised of porosity should not be negative either thus giving rise to another feasibility test. It has been found, however, that some small statistical variation of the porosity percentage below zero percent can be tolerated without unduly affecting the overall accuracy of the computations.

To accomplish the above objects with the Figure 1 system the parameters 2-4 output signals from matrix computer No. 1 are applied to parallel polarity detectors 50 which will individually generate an output signal whenever the corresponding input signal is zero or positive. These output signals from polarity detectors 50 are applied to an AND gate 51. Parameter No. 1, which from Table I, is water-filled porosity, is supplied to a voltage discriminator 52, which operates to generate an output signal when the water-filled porosity is above a given negative voltage level. The output signal from the discriminator 52 is also applied to the AND gate 51. The output signal from AND gate 51 constitutes the output signal from the feasibility test circuit No. 1. This output signal is applied to the OR gate 35 and a parallel voltage generator 40. If the computations made by matrix computer No. 1 are deemed to be feasible, the feasibility test circuit No. 1 will generate an output signal via OR gate 35 to energize the gate 49 and thus apply the output signals from matrix computer No. 1 to the buffer memory 48. The output

signal from feasibility test circuit No. 1 also resets the counter 27 to its "0" state and resets the flip-flop 36 so as to inhibit the clock pulses from further advancing the counter 27.

5 The output signal from feasibility test circuit No. 1 also energizes a selected voltage generator of the parallel voltage generator 40 so as to cause a signal having a given amplitude to be applied to the recorder 31 to indicate the

10 fact that matrix set No. 1 has been selected by the system. The system then waits for the next depth pulse to perform the same operation from well logging measurements derived at the next depth level.

15 If, one or more of the output signals from matrix computer No. 1 had failed to satisfy the feasibility test applied by feasibility test circuit No. 1, the next clock pulse from clock 38 would have advanced the counter to state

20 No. 2 so as to energize the gates 20 and thus enable matrix computer No. 2 to operate. The feasibility test circuit No. 2 then checks the feasibility of the computations made by matrix computer No. 2 and initiates the reset of the

25 system and read out of the computations to recorder 31 if the computations are feasible. If the computations are not feasible, the system is allowed to continue to matrix computer No. 3.

30 At this point, a decision must be made whether to proceed to matrix set No. 3 or to bypass this set to go to matrix set No. 4. From Table I, it can be seen that parameter No. 2 is gas-filled porosity in matrix set No. 3 and coal in matrix set No. 4. To determine which

35 matrix set to choose, the value of the lithology indicator "N" is computed by a computer 55. The definition of "N" and the construction of this N computer can be found in U.S. Patent No. 3590228 issued to J. A. Burke on

40 June 29th 1971. If the computed value of N is below a given critical or cutoff value N_c , it has been found that it can reasonably be assumed that there is a greater likelihood of gas being present in the formation than coal and thus

45 matrix No. 3 is selected. If, on the other hand, N is greater than N_c , there is a greater likelihood of coal being present in the formation and thus matrix No. 4 is selected.

50 To accomplish this selection process in the system of Figure 1, the computed value of N from the N computer 55 is applied to a voltage discriminator 56 which generates an output signal only if N is less than N_c . In this event, the discriminator 56 enables an AND gate 57

55 to pass the gate control signal from counter 27 to the gates 21 so as to enable matrix computer No. 3 to operate. On the other hand, if N is greater than N_c , the output voltage from the discriminator 56, which will be zero, enables

60 an AND gate 58 via a voltage inverter 59. Once AND gate 58 is enabled, the No. 4 output signal from counter 27 enables the gates 22 so as to allow the matrix computer No. 4 to operate. The feasibility test circuits No. 3 and

65 No. 4 operate in a similar manner to the feasibility

circuits No. 1 and No. 2 and thus need not be discussed.

If no feasible answers have been produced by the first four matrix sets, the system reads out to the recorder 31 the computations stored in the buffer memory 48 from the last depth level where feasible answers were obtained and resets the counter 27 and flip-flop 36 in readiness for another depth pulse from depth pulse generator 28. This is accomplished in Figure 1 by the counter 27 producing an output signal at the output terminal 4A after the first four matrix sets have been considered. This output signal on output terminal 4A operates to reset the counter 27 and the flip-flop 36. The diode 35a prevents the gates 49 from being energized and since buffer memory 48 contains all of the data computed at the last depth level, the data fed to the recorder 31 will be the computations made at the last depth level where feasible answers were obtained.

When using matrix computers 1 through 4, it is assumed that the SP voltage is greater than SP_c . Assume now that SP is equal to or less than SP_c . In this event, the AND gate 46 will be enabled and each depth pulse from depth pulse generator 28 will set the counter 27 to the No. 5 state so that the first four matrix computers will be bypassed and matrix set No. 5 will be the first matrix set to be considered. Thus, in this event, the No. 5 terminal of counter 27 generates a signal which energizes the gates 23 to enable the matrix computer No. 5 to operate. The computations produced by matrix computer No. 5 are tested by the feasibility test circuit No. 5. In addition to the tests made by the feasibility test circuit No. 1, the feasibility test circuit No. 5 also checks to determine if the water-filled porosity ϕ_w is greater than some cut-off value, say 8%, and if so, the computations made by matrix computer No. 5 are deemed to be not feasible. The reason for this is that it has been found that if SP is less than SP_c and ϕ_w is greater than the ϕ_w (cut-off value), designated ϕ_{wc} , the computations are probably inaccurate.

In the feasibility test circuit No. 5, the parameter Nos. 2, 3 and 4 output signal from matrix computer No. 5 are applied to polarity detectors 50a and the parameter No. 1 signal is applied to a discriminator 52a. These circuits 50a and 52a operate in the same manner and for the same purpose as circuits 50 and 52 of feasibility test circuit No. 1. In addition to the circuits of feasibility test circuit No. 1, feasibility test circuit No. 5 also includes a discriminator 52b which generates an output signal only when the water-filled porosity value ϕ_w is greater than ϕ_{wc} . The output signals from polarity detectors 50a and discriminators 52a and 52b are applied to the input of an AND gate 51a whose output signal constitutes the output signal from feasibility test circuit No. 5.

If the computations made by matrix computer No. 5 are feasible, the system is reset and

the buffer memory 48 updated, as before. If not feasible, the system proceeds to matrix computer No. 6 whereupon the percent of bulk volume of the formation parameters listed for matrix No. 6 in Table I are computed. If the computations produced by matrix computer No. 6 are not feasible, the system proceeds from one matrix computer to another until it either finds feasible answers or reaches matrix computer No. n. From Table I, it can be seen that quartz has been substituted for water-filled porosity in matrix No. n. In other words, the system has by this time tried every possible combination of parameters and is now ready to assume that porosity is insignificant as compared to a selected mineral (in this case, quartz) at the particular depth level being considered. If matrix computer No. n does not produce feasible answers, the counter 27 will advance to the $n+1$ state and reset the system in readiness for the next depth pulse from depth pulse generator 28. The diode 35a prevents the gates 49 from being energized and thus buffer memory 48 would not be updated since valid answers were not obtained for the depth level under consideration.

If desired, the buffer memory 48 could be reset to zero whenever feasible answers are not obtained. This is represented in Figure 1 by the dotted line connecting terminals 4A and $n+1$ of counter 27 to the reset input of buffer memory 48. In this event, suitable isolation diodes would be necessary to prevent an output signal from OR gate 35 from resetting the memory.

Additionally, any well logging measurement could be utilized to aid in determining which matrix set or group of matrix sets are most probable. The present invention is not limited to just the examples using SP and N which were discussed above. Thus, for example, as illustrated in dotted line form in Figure 1, a gamma-ray measurement could be made and if greater than some critical value GR_c , the system could be made to consider some predetermined group of matrix sets.

Turning now to Figure 2, there is shown apparatus which can be added onto the system of Figure 1 to compute various desirable parameters in addition to those already discussed. These additional parameters are effective porosity ϕ_e ; the percentage of the total porosity filled with clay, designated q ; and the water saturation S_w . This added on circuitry of Figure 2 is located between the output of the combining circuit and the gates 49. In Figure 2, the gates 49, buffer memory 48 and recorder 31 are designated 49a, 48a and 31a respectively (instead of 49, 48, and 31) to indicate the fact that more signals are being processed. Otherwise, these three devices are the same as in Figure 1. The gates 49a are energized by the same "gate enable pulse" which enables the gates 49 in Figure 1. The counter 27 is the same as the similarly designated element of Figure 1. The remainder of the Figure 1 circuitry has been omitted as being unnecessary to the explanation of Figure 2 but is nevertheless assumed to be part of the Figure 2 circuitry. Thus, the counter 27 is energized and reset in the same manner as in Figure 1 and the combining circuit 30 derives its input signals in the same manner as in Figure 1.

To compute the effective porosity, the system of Figure 2 combines the water-filled porosity ϕ_w and the gas-filled porosity ϕ_g in accordance with the following expression:

$$\phi_e = \phi_w + \phi_g \quad (9)$$

The expression for the percentage of total porosity filled with clay is:

$$q = \frac{\phi_{cl}}{\phi_{cl} + \phi_w + \phi_g} \quad (10)$$

The equation for the water saturation S_w is:

$$S_w = \frac{.5}{\phi_e} \left[-q\phi_e + \sqrt{(q\phi_e)^2 + \frac{3.24 R_w}{R_t} (1 - V_{sh}) 1 - \frac{V_{sh} R_t}{R_{sh}}} \right] \quad (11)$$

where

$$\phi_e = \phi_{cl} + \phi_w + \phi_g \quad (12)$$

V_{sh} is the bulk volume of laminated shale, and

R_{sh} is the true resistivity of the shale lamina.

The Nos. 1—4 parameters from combining circuit 30 are all applied to the gates 49a for application to the buffer memory 48a and recorder 31 in the same manner as in Figure 1.

In Figure 2, to compute the value of effective porosity ϕ_e , the No. 1 parameter from combining circuit 30 is applied to an adding circuit 60. The No. 2 parameter is gated to the adding circuit 60 during period 3 (corresponding to matrix No. 3) by the No. 3 output signal from counter 27 energizing a gate circuit 61. As seen from Table I, gas-filled porosity is a formation parameter used only in matrix No. 3 during period 3. Thus, adding circuit 60

combines ϕ_w and ϕ_s in accordance with Equation (9) to produce a signal proportional to the effective porosity ϕ_e for application to the gates 49a. In the event that a matrix other than matrix No. 3 is used, ϕ_s will be zero and thus ϕ_w will be equal to ϕ_e .

To compute the percentage of the total porosity filled with clay (q), parameter No. 3 is gated to an adding circuit 62 by a gate 63 only during periods 2, 7 and n. From Table I, parameter 3 of matrixes 2, 7 and n is the dispersed clay indication ϕ_{cl} . Additionally, the effective porosity ϕ_e from adding circuit 60 is applied to the adding circuit 62 so that the output signal from adding circuit 62 will be proportional to the total porosity ϕ_t . This total porosity indication ϕ_t is divided into the clay porosity indication ϕ_{cl} by a dividing circuit 64 in accordance with Equation (10) to produce a signal proportional to q for application to the gates 49a. In accordance with Equation (11), the quantities q, ϕ_s , and ϕ_e are applied to an S_w computer 65. Additionally, the percentage of parameter No. 4, which from Table I is the bulk volume of laminated shale (V_{sh}) during all periods, is also applied to the S_w computer 65. Of course, if parameter No. 4 were something other than laminated shale during some periods of operation, parameter No. 4 from combining circuit 30 should be gated to the S_w computer 65 during only those pertinent periods of operation.

To supply the values of R_t and R_w to the S_w computer 65, a playback recorder 70 which had previously recorded values of R_t and R_w during a previous logging run, is driven by the shaft 32 so as to generate values of R_t and R_w in synchronism with the movement of the exploring device 10 through the borehole. The computed value of S_w from computer 65 is also applied to the gates 49a for application to buffer memory 48 at the proper time.

As in the Figure 1 system, the "gate enable pulse" generated from the OR gate 35 of Figure 1 energizes the gates 49a to enable the buffer memory 48a to store the signals from the gates 49a for application to the recorder 31. As in the Figure 1 system, if feasible results cannot be obtained, the gates 49a will never be energized and the buffer memory 48a will not be updated.

Now turning to Figure 3, there are shown examples of typical logs which could be produced by the system of Figures 1 and 2. In Figure 3, track 1 is a log of the percent of bulk volume of each of the formation parameters listed in Table I, the three individual curves of track 1 representing the percentage boundaries between the parameters. Thus, the bulk volume of laminated shale is represented by the cross hatched portion of the log, while the distance between the rightmost curve of the log and the extreme right-hand edge of the log represents water-filled porosity ϕ_w .

To determine which parameters are being

recorded in track 1, there is a "matrix set log" recorded in track No. 2. This matrix set log is the solid line curve in track No. 2. The voltage level of this matrix set log is indicative of which matrix set is being recorded at any given depth level in track 1. Also recorded in track 2 is the dispersed clay "q" curve which, as stated earlier, is representative of that fraction of the total porosity which is filled with clay. The effective porosity ϕ_e and water saturation S_w logs are recorded in track 3 to complete the picture of the makeup of the earth formations under investigation. How these logs can be utilized as an aid in evaluating earth formation is well known and need not be discussed here.

Now turning to Figures 4A and 4B, there is shown a flow chart representation of the techniques of the present invention which flow chart could be utilized to program a general purpose digital computer (Figure 4A fits on top of Figure 4B to make a complete diagram of Figure 4. Hereafter, Figures 4A and 4B will be referred to as Figure 4). In Figure 4, the constant formation parameters are read as represented by the box 70. These formation parameters comprise, for example, the acoustic travel time of the formation fluids, the hydrogen index of the fluids, the water resistivity, etc. Next, the well logging measurements Δt , ρ_B , ϕ_N and SP are read for a given depth level, as represented by the block 71. Next, a test is made to determine if SP is equal to or less than the critical SP value, as represented by the decision block. If SP is not equal to or less than SP_c , the percentages of the formation parameters are computed in accordance with matrix No. 1 of Table I, as indicated by the block 73. As indicated by the decision block 74, a test is then made to determine if the computations for parameters 2-4 are negative and if the water-filled porosity ϕ_w is less than the critical value of water-filled porosity ϕ_{wc} . If not, the values of S_w , q and ϕ_e are computed in accordance with Equations (9), (10) and (11), as indicated by the block 75. As indicated by the block 76 and circle 77, the results are then printed out and the system goes back to start. Since the so-called "constant formation parameters" are generally constant over large sections of the borehole, the system could be made to omit the box 70 until reaching a depth level where new "constant formation parameters" are called for.

If the decision block 74 indicates "yes", the percentages of the formation parameters are computed with matrix No. 2 of Table I, as indicated by block 78. As indicated by decision block 79, the feasibility of the answers provided from matrix No. 2 are tested. If feasible, the values of q, ϕ_e , and S_w are computed and the results of this computation as well as the percentages of bulk volume percentage of each of the formation parameters are printed out and the system goes back to start to perform

the operation again for the next depth level, as indicated by elements 80, 81 and 82.

If the answer from decision block 79 is yes, the lithology indicia "N" is computed as represented by the block 83. Next, as indicated by the decision block 84, this value of N is checked to determine if it is greater than the critical value of N_c . If N is less than N_c , the formation parameters are computed with matrix No. 3 of Table I as represented by the block 85. If N is greater than N_c , the formation parameters are computed with matrix No. 4 as represented by the block 86. In both cases, the feasibility of the results are checked as indicated by decision blocks 87 and 88 and the computed formation parameters q , ϕ_s and S_w are computed as represented by the blocks 89 and 90. In both cases the results are printed out and the system proceeds back to start if feasible answers were obtained. If not, the system proceeds from one matrix to the next using as many ancillary tests (e.g., $SP \geq SP_c$, $GR \geq GR_c$, $N \geq N_c$) are necessary or desirable. If no feasible answers are obtained, the results from the last depth level which produced feasible results are printed out and the system goes back to start, as represented by elements 93 and 94.

Referring back to the decision block 72, if SP was equal to or less than SP_c , the percentages of the formation parameters are computed with matrix No. 5 of Table I as represented by the block 95. As represented by the decision block 96, the percentage of the formation parameters are checked to determine if the parameters 2—4 are negative and if ϕ_w is less than ϕ_{wc} . If these tests are satisfied, a test is made to determine if ϕ_w is greater than the upper limit value of ϕ_w , ($\phi_{w(max)}$), as represented by the decision block 105. If not greater, q , ϕ_s and S_w are computed, the results printed out, and the system goes back to start as represented by elements 97, 98 and 99. If, on the other hand, any one of these feasibility tests was failed, the percentages of formation parameters are computed with matrix No. 6 as represented by block No. 100. Again, the computed answers are tested for feasibility as represented by the decision block 101 and if feasible, S_w , q and ϕ_s are computed, the results printed out and the system proceeds back to start, as represented by elements 102, 103 and 104.

If the percentages of the formation parameters computed with matrix No. 6 fail to pass the feasibility test, the formation parameters are computed with matrix No. 7 of Table I as represented by block 107 and checked for feasibility by the decision block 108. If the answers are feasible, q , ϕ_s and S_w are computed, the results printed out and the system goes back to start as represented by elements 109, 110 and 111. If the results were not feasible, the system can continue using other matrixes, or other tests, until either feasible answers are

obtained or the system reaches matrix N and still cannot find feasible answers in this event, as represented by block 93 and circle 94, the results from the last depth level which produced feasible results are used and the system goes back to start.

It can be seen from the foregoing description that a technique has been set forth for determining the parameters of a formation and computing what portion of a formation is contributed by each parameter; this has been accomplished by determining the makeup of any given formation by using matrix sets of four parameters each which sets are arranged in the order of probability of their occurrence in any given formation. By checking the feasibility of the computations produced by each matrix set and proceeding to the next matrix set if the results are not feasible, as well as by utilizing measurements of various other formation parameters as an aid in selecting the proper matrix, it is possible to accurately determine the parameters of any given formation and compute their percentage contribution to such a formation.

While there have been described what are at present considered to be preferred embodiments of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the scope of the appended claims.

WHAT WE CLAIM IS:—

1. A method of producing electrical signals representative of characteristic properties of an earth formation which is traversed by a borehole and is made up of an unknown set of formation parameters, comprising the steps of:

deriving electrical measurement signals respectively representative of measurements of plural characteristics of an earth formation at a depth level;

combining such measurement signals to produce first electrical signals representative of respective proportions of formation parameters computed for said earth formation on the assumption that said formation is made up of a first predetermined set of formation parameters;

testing the feasibility of said first computed proportions represented by said first signals;

combining such derived measurement signals to produce second electrical signals representative of respective proportions of formation parameters computed for said earth formation on the assumption that said formation is made up of a second predetermined set of formation parameters, if said first computed proportions are not feasible; and

testing the feasibility of said second computed proportions represented by said second signals, whereby to select said first electrical signals as an indication of the true formation parameters at the depth level if the first com-

the operation again for the next depth level, as indicated by elements 80, 81 and 82.

If the answer from decision block 79 is yes, the lithology indicia "N" is computed as represented by the block 83. Next, as indicated by the decision block 84, this value of N is checked to determine if it is greater than the critical value of N_c . If N is less than N_c , the formation parameters are computed with matrix No. 3 of Table I as represented by the block 85. If N is greater than N_c , the formation parameters are computed with matrix No. 4 as represented by the block 86. In both cases, the feasibility of the results are checked as indicated by decision blocks 87 and 88 and the computed formation parameters q , ϕ_e and S_w are computed as represented by the blocks 89 and 90. In both cases the results are printed out and the system proceeds back to start if feasible answers were obtained. If not, the system proceeds from one matrix to the next using as many ancillary tests (e.g., $SP \geq SP_c$, $GR \geq GR_c$, $N \geq N_c$) are necessary or desirable. If no feasible answers are obtained, the results from the last depth level which produced feasible results are printed out and the system goes back to start, as represented by elements 93 and 94.

Referring back to the decision block 72, if SP was equal to or less than SP_c , the percentages of the formation parameters are computed with matrix No. 5 of Table I as represented by the block 95. As represented by the decision block 96, the percentage of the formation parameters are checked to determine if the parameters 2—4 are negative and if ϕ_w is less than $\phi_{w_{max}}$. If these tests are satisfied, a test is made to determine if ϕ_w is greater than the upper limit value of ϕ_w , ($\phi_{w_{max}}$), as represented by the decision block 105. If not greater, q , ϕ_e and S_w are computed, the results printed out, and the system goes back to start as represented by elements 97, 98 and 99. If, on the other hand, any one of these feasibility tests was failed, the percentages of formation parameters are computed with matrix No. 6 as represented by block No. 100. Again, the computed answers are tested for feasibility as represented by the decision block 101 and if feasible, S_w , q and ϕ_e are computed, the results printed out and the system proceeds back to start, as represented by elements 102, 103 and 104.

If the percentages of the formation parameters computed with matrix No. 6 fail to pass the feasibility test, the formation parameters are computed with matrix No. 7 of Table I as represented by block 107 and checked for feasibility by the decision block 108. If the answers are feasible, q , ϕ_e and S_w are computed, the results printed out and the system goes back to start as represented by elements 109, 110 and 111. If the results were not feasible, the system can continue using other matrixes, or other tests, until either feasible answers are

obtained or the system reaches matrix N and still cannot find feasible answers in this event, as represented by block 93 and circle 94, the results from the last depth level which produced feasible results are used and the system goes back to start.

It can be seen from the foregoing description that a technique has been set forth for determining the parameters of a formation and computing what portion of a formation is contributed by each parameter; this has been accomplished by determining the makeup of any given formation by using matrix sets of four parameters each which sets are arranged in the order of probability of their occurrence in any given formation. By checking the feasibility of the computations produced by each matrix set and proceeding to the next matrix set if the results are not feasible, as well as by utilizing measurements of various other formation parameters as an aid in selecting the proper matrix, it is possible to accurately determine the parameters of any given formation and compute their percentage contribution to such a formation.

While there have been described what are at present considered to be preferred embodiments of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the scope of the appended claims.

WHAT WE CLAIM IS:—

1. A method of producing electrical signals representative of characteristic properties of an earth formation which is traversed by a borehole and is made up of an unknown set of formation parameters, comprising the steps of:

deriving electrical measurement signals respectively representative of measurements of plural characteristics of an earth formation at a depth level;

combining such measurement signals to produce first electrical signals representative of respective proportions of formation parameters computed for said earth formation on the assumption that said formation is made up of a first predetermined set of formation parameters;

testing the feasibility of said first computed proportions represented by said first signals;

combining such derived measurement signals to produce second electrical signals representative of respective proportions of formation parameters computed for said earth formation on the assumption that said formation is made up of a second predetermined set of formation parameters, if said first computed proportions are not feasible; and

testing the feasibility of said second computed proportions represented by said second signals, whereby to select said first electrical signals as an indication of the true formation parameters at the depth level if the first com-



puted proportions are feasible and said second electrical signals as such indication if said first computed proportions are not feasible and said second computed proportions are feasible.

2. The method of claim 1, including repeating the steps of testing the feasibility of computed formation proportions and combining such derived measurement signals to produce electrical signals representative of formation proportions computed for said formation made up of another predetermined set of formation parameters if the last tested computed proportions are not feasible, until a set of formation parameters has been used which yields feasible computed proportions.

3. The method of claim 1 or 2 further including the step of recording electrical signals representative of the proportions computed for whichever set of formation parameters, if any, produced feasible computed proportions.

4. The method of any of the preceding claims, wherein each step of testing the feasibility of said first computed proportions includes generating a feasibility test electrical signal representative of the feasibility of said first computed proportions, and the second step of combining such derived measurement signals is performed in response to said feasibility test signal indicating that said first computed proportions are not feasible.

5. The method of claim 4, wherein the step of generating said feasibility test signal includes generating a signal indicative of the non-feasibility of said first computed proportions upon at least one signal representative of a selected one of said first computed proportions exceeding a predetermined limit.

6. The method of any of the preceding claims, wherein said derived measurement signals include signals respectively representative of the acoustic travel time, hydrogen content, and bulk density of a formation at a selected depth level.

7. The method of claim 6, wherein said computed formation proportions are the bulk volume percentages P_1 , P_2 , P_3 and P_4 of the formation parameters of said sets, and are computed in accordance with the expressions

$$\begin{aligned} k_1 \Delta t &= P_1 \Delta t_1 + P_2 \Delta t_2 + P_3 \Delta t_3 + P_4 \Delta t_4 \\ k_2 H &= P_1 H_1 + P_2 H_2 + P_3 H_3 + P_4 H_4 \\ k_3 \rho_B &= P_1 \rho_{B1} + P_2 \rho_{B2} + P_3 \rho_{B3} + P_4 \rho_{B4} \\ 1 &= P_1 + P_2 + P_3 + P_4 \end{aligned}$$

where Δt , H and ρ_B are values of acoustic travel time, hydrogen index and bulk density of said formation measured at a selected depth level, k_1 , k_2 and k_3 are calibration constants of exploring devices which measure Δt , H and ρ_B respectively, and Δt_1 , H_1 , ρ_{B1} , etc. are constants representative of the responses of the particular exploring devices to each parameter.

8. The method of any preceding claim, further including the steps of generating a set indicator signal indicative of which set of

formation parameters is to be used as an indication of the true formation parameters, and recording said set indicator signal.

9. The method of claim 3 and any other preceding claim, further including the step of recording signals representative of formation proportions computed for a previously considered depth level if feasible computed proportions are not obtained at the depth level presently under consideration.

10. The method of any preceding claim, further including the steps of using at least one of said derived measurement signals to determine which one of a plurality of formation parameter sets or groups of such sets is most probable in said earth formation, and thereafter, producing electrical signals representative of such computed proportions by using the most probable formation parameter set, or one set of the most probable group of sets.

11. The method of claim 10, wherein the next most probable set, or set of the most probable group, is used for producing said second electrical signals, after said first electrical signals have been produced by using a first predetermined set, if said first computed proportions are not feasible.

12. The method of claim 10, wherein one of said derived measurement signals is representative of the spontaneous potential or natural radioactivity of the formation at the depth level and the step of determining the most probable set or group of sets of formation parameters includes the steps of selecting one set or group of sets as the most probable if said spontaneous potential or natural radioactivity measurement is greater than a selected reference value, and selecting another set or group of sets of formation parameters as the most probable if said spontaneous potential or natural radioactivity measurement is less than said selected reference value.

13. The method of claim 10 or 11, wherein two of the derived measurement signals are respectively representative of the hydrogen content and bulk density of the formation at the depth level, and wherein the step of using at least one of said derived measurement signals to determine which set or group of sets is most probable includes the steps of: using said measurement signal representative of the hydrogen content of said formation to produce a signal representative of the porosity ϕ_N at the depth level; using said ϕ_N representative signal and said measurement signal representative of the bulk density ρ_B for producing a signal representative of a lithology indicator N in accordance with the expression:

$$N = \frac{H_F - \phi_N}{\rho_B - \rho_F}$$

where H is the hydrogen index of the formation interstitial fluid and ρ_F is the bulk density



of the interstitial fluid; selecting one set or group of sets of formation parameters if N is greater than a selected reference value; and selecting another set or group of sets of formation parameters if N is less than a selected value.

14. The method of any of claims 1 to 9, wherein said first and second sets of predetermined formation parameters belong to a sequence of formation parameter sets ordered for use in computing said formation proportions in accordance with the probability of occurrence in said formation of the formation parameters which make up each set.

15. The method of any of the preceding claims, including the step of using electrical signals representative of selected ones of the computed proportions for the set indicating the true formation parameters of said formation for producing signals representative of the effective porosity and amount of clay in said formation.

16. The method of claim 15, wherein one of said derived measurement signals is representative of the resistivity of the formation and further including the step of combining said signals representative of the effective porosity and amount of clay with said resistivity measurement signal to produce a signal representative of the water saturation of the formation.

17. Apparatus for processing data representative of an earth formation traversed by a borehole, comprising:

means for deriving measurements of a plurality of characteristics of an earth formation;

means responsive to said measurements for computing the proportions of formation parameters of said earth formation on the assumption that said formation is made up of a first set of formation parameters and generating output signals representative thereof;

means responsive to said output signals for testing the feasibility of said formation parameter proportion computations and generating a feasibility test signal representative thereof; and

means responsive to said measurements and said feasibility test signal for computing the proportions of formation parameters of said formation on the assumption that said formation is made up of a second predetermined set of formation parameters if the computations

using said first set of formation parameters are not feasible.

18. The apparatus of claim 17 wherein the means for deriving measurements includes means for measuring the acoustic travel time of a formation at a selected depth level in a borehole, means for measuring the hydrogen content of said formation at said depth level, and means for measuring the bulk density of said formation at said depth level.

19. The apparatus of claim 18 wherein the means for computing said formation parameter portions includes means for computing the bulk volume percentages P_1 , P_2 , P_3 and P_4 of selected formation parameters in accordance with the expressions:

$$k_1 \Delta t = P_1 \Delta t_1 + P_2 \Delta t_2 + P_3 \Delta t_3 + P_4 \Delta t_4$$

$$k_2 H = P_1 H_1 + P_2 H_2 + P_3 H_3 + P_4 H_4$$

$$k_3 \rho_B = P_1 \rho_{B1} + P_2 \rho_{B2} + P_3 \rho_{B3} + P_4 \rho_{B4}$$

$$1 = P_1 + P_2 + P_3 + P_4$$

where Δt , H and ρ_B are the measured values of acoustic travel time, hydrogen index and bulk density of said formation, k_1 , k_2 and k_3 are calibration constants of said means for measuring Δt , H and ρ_B respectively, and Δt_1 , H_1 , ρ_{B1} , etc. are constants representative of the responses of the particular measuring means to each parameter.

20. The apparatus of any of claims 17 to 19 further including means of causing said computing means to compute such formation parameter proportions using ordered sets of predetermined formation parameters, said sets being ordered in accordance with the probability of occurrence in said formation of the formation parameters which make up each set.

21. Method of producing electrical signals representative of characteristic properties of an earth formation, which method is substantially as described hereinbefore with reference to and as illustrated in the accompanying drawings.

22. Apparatus for processing well logging data substantially as described hereinbefore with reference to and as illustrated in the accompanying drawings.

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