June 4, 1968 O. T. MOORE 3,386,286

HYDROCARBON WELL LOGGING

Filed March 18, 1966 4 Sheets-Sheet 1

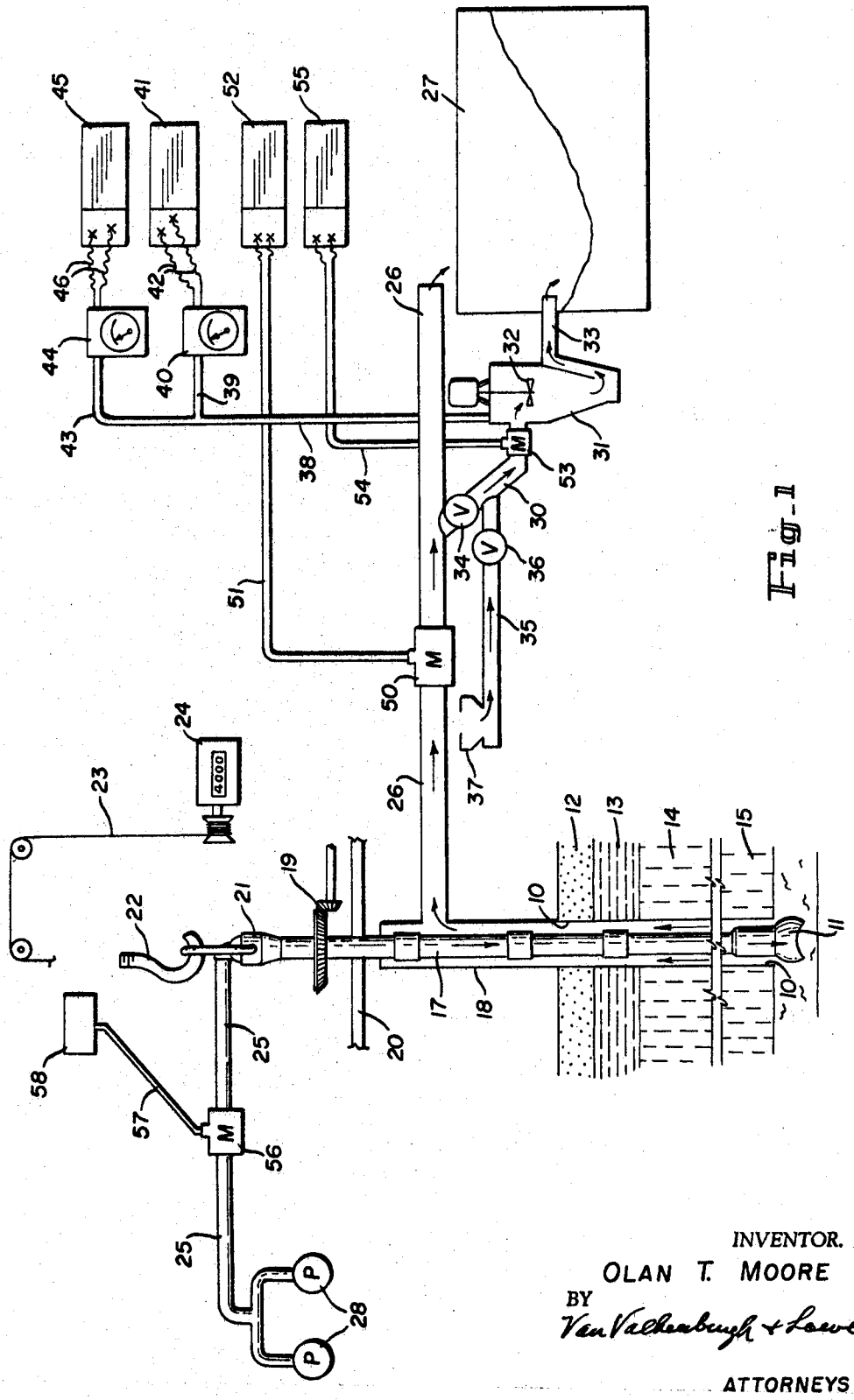


Fig. 1

INVENTOR.
OLAN T. MOORE
BY
Van Valkenburgh + Lowe
ATTORNEYS

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HYDROCARBON WELL LOGGING

Filed March 18, 1966 4 Sheets-Sheet 2

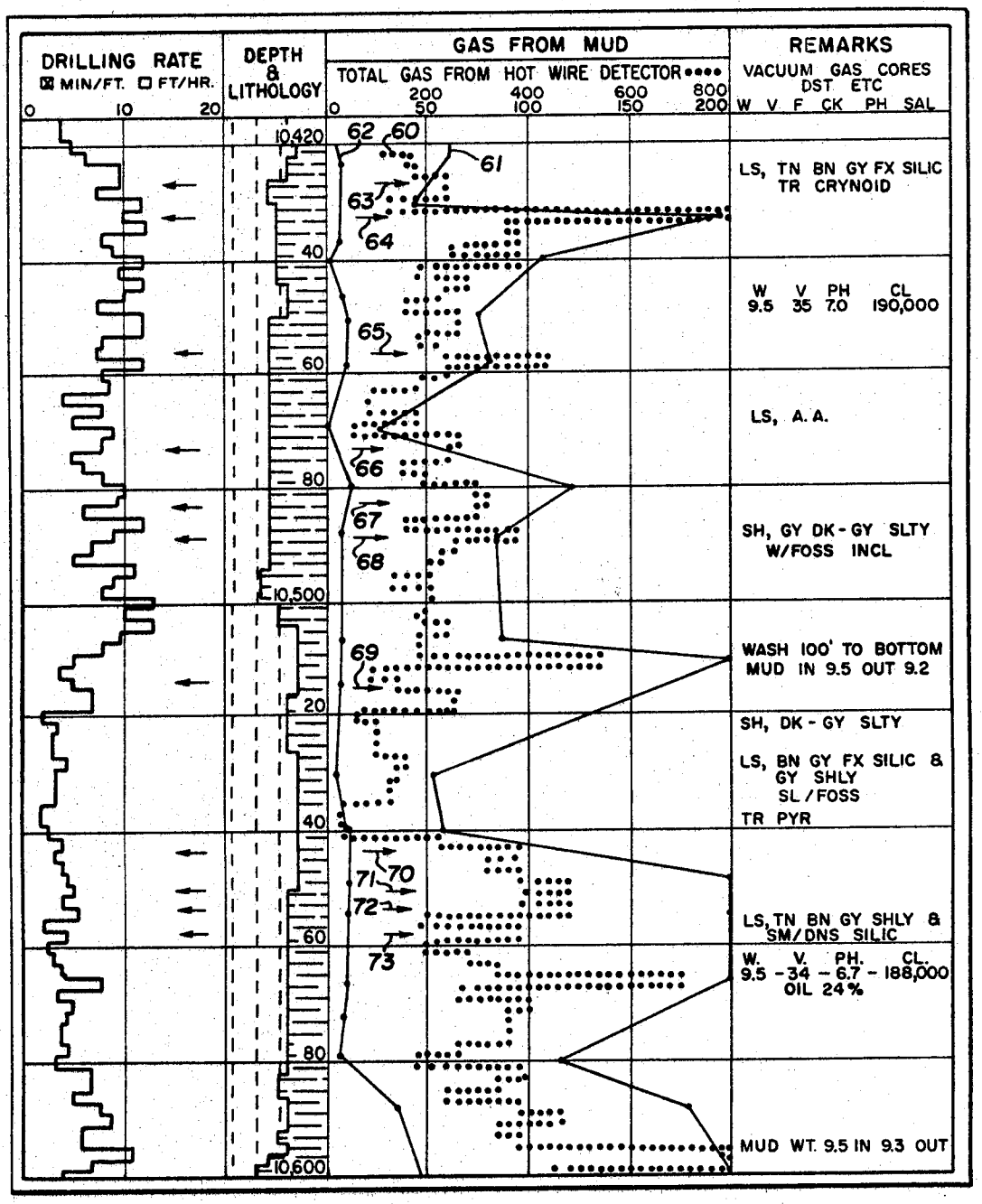


Fig. 2

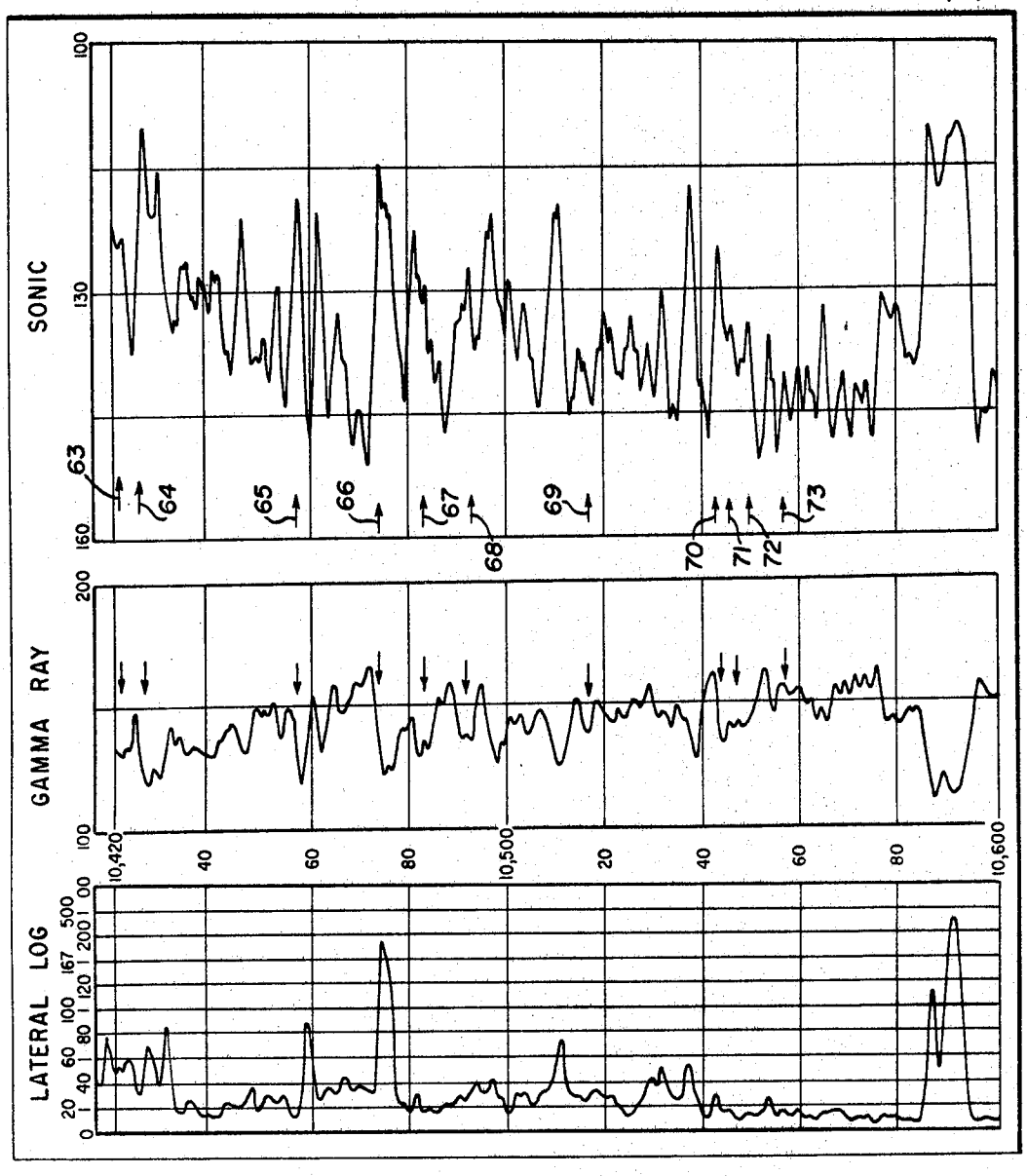
INVENTOR.
OLAN T. MOORE
BY
Van Valkenburgh & Lowe
ATTORNEYS

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HYDROCARBON WELL LOGGING

Filed March 18, 1966 4 Sheets-Sheet 3

Fig-3



INVENTOR.

OLAN T. MOORE

BY

Van Valkenburgh & Lowe

ATTORNEYS

June 4, 1968 O. T. MOORE 3,386,286

HYDROCARBON WELL LOGGING

Filed March 18, 1966 4 Sheets-Sheet 4

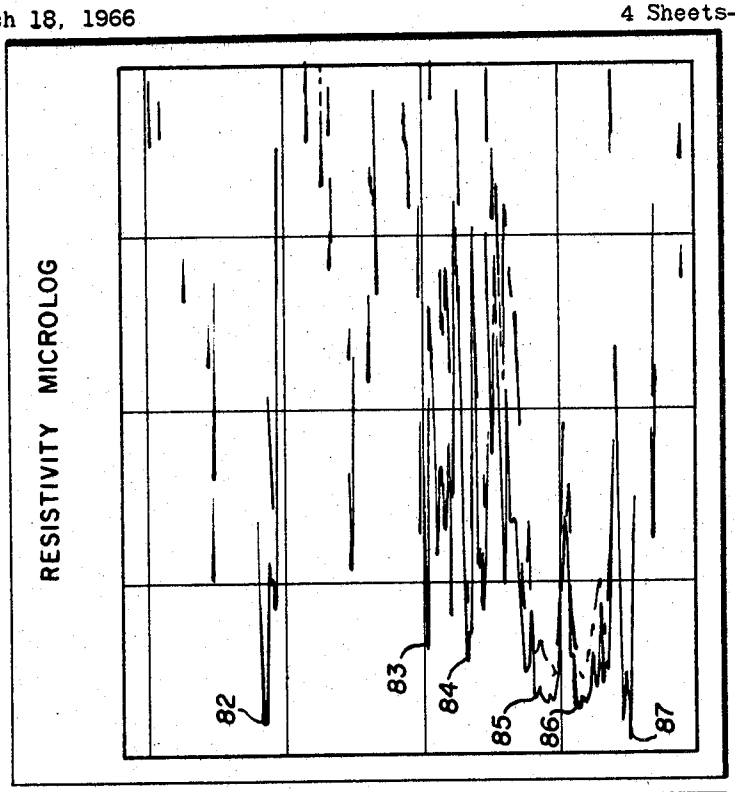


Fig-5

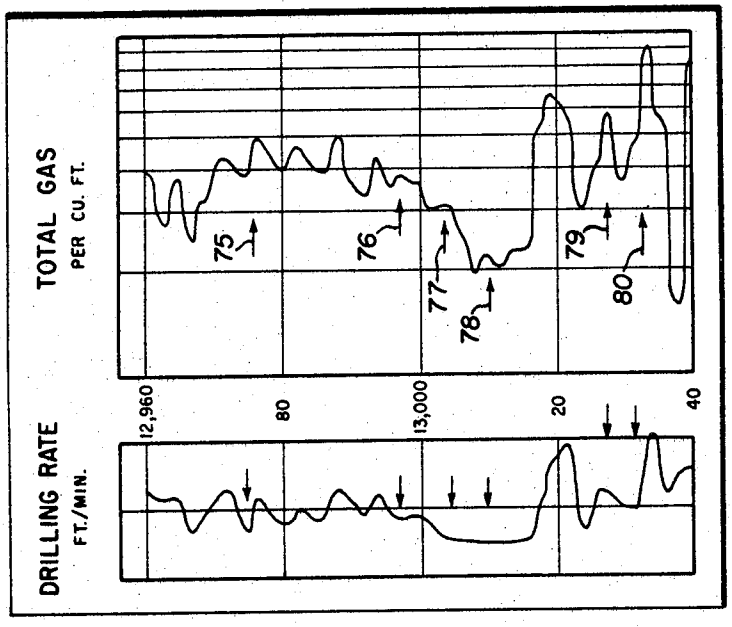


Fig-4

INVENTOR.
OLAN T. MOORE
BY
Van Vachenburgh & Lowe
ATTORNEYS

United States Patent Office 3,386,286
Patented June 4, 1968

3,386,286

HYDROCARBON WELL LOGGING

Olan T. Moore, P.O. Box 3297,
Midland, Tex. 79701

Filed Mar. 18, 1966, Ser. No. 535,423
7 Claims. (Cl. 73—153)

ABSTRACT OF THE DISCLOSURE

A hydrocarbon well logging method which includes, in addition to the usual depth measurements, mud flow measurement and detection of hydrocarbon gases in the diverted portion of the mud, the steps of measuring the total flow rate of mud, the flow rate of diverted mud and correlatively recording the total relative amount of gas for the mud flowing through increments of the well bore, in order to obtain the relative gas content of each volumetric increment of the formation through which the well is drilled. In addition the relative amount of total methane, ethane and propane, as well as the relative amount of normal butane, isobutane, normal pentane and isopentane may be recorded.

This invention relates to hydrocarbon well logging.

In the normal drilling of an oil or gas well, a drill bit, which is rotated by a drill string, bores a hole downwardly through successive formations, until one or more oil or gas producing zones are encountered, or the well is abandoned. A mixture, as of water or oil and other ingredients, which forms a mud, is normally circulated down the drill string, out through the bit and then up the hole, although under certain circumstances, a reverse circulation, i.e., passing the mud down the hole and back up through the drill string, may be utilized. The mud not only lubricates the drill bit, but also provides a sufficient pressure to prevent oil or gas under pressure encountered in a lower formation from blowing the mud out of the well, or salt water or the like from flowing into the well. Sometimes, the mud seals off a producing formation, so that such a formation may be difficult to detect. An experienced driller can often tell by the resistance to drilling the general type of formation encountered, while the cuttings, which are small particles of the formation reduced in size by the drill bit and carried up the hole by the mud, give an indication of the lithology or type of formation encountered. Oftentimes, when a formation which is suspected of being oil or gas producing is encountered, a core is taken, so that the actual formation may be more accurately determined.

Since the geologist or other person in charge of drilling the well cannot be personally at the bottom of the well and either observe or test the formation being drilled through, it is necessary that all available information indicative of the presence of an oil or gas producing zone be made available. Such information is never conclusive of the presence of an oil or gas producing zone, so that the greater the amount of information available, the greater the possibility of a producing zone being identified. If a producing zone is suspected, a drill stem test is sometimes made, in which the mud pressure is reduced, so that oil or gas in a suspected producing zone will have an opportunity to escape into the well and come to the surface. There are, of course, various well known stratagems, primarily involving packers, by which a section of the well may be isolated for such a drill stem test.

One way in which a considerable amount of information about the character and propensities of the formations drilled through may be obtained is by electric logging, involving the lowering of an instrument down the well, by which successive portions of the well bore wall

are subjected to electrical resistivity tests, gamma ray tests, neutron tests, sonic tests and the like. However, the lowering of such an instrument in the well requires that the drill string be removed from the well and thus can ordinarily be made only when the bit is changed or casing is to be installed, without otherwise interrupting the drilling operation. Electric logs are commonly run just before casing is set, as at 5,000 ft., before the size of the drill bit is reduced, again at 12,000 ft. or a higher elevation, if the bit size is changed, and finally when the bottom of the hole is reached. Since the gamma ray and neutron logs can be run with casing in the well, but other electric logs cannot, it is desirable to run electric logs without casing in the portion being logged. Even in an exploratory or "wildcat" well, such electrical logs are usually made at the same depths. In a wildcat well, the formations encountered are generally unknown, even though the general contour and general depth of various formation layers may have been reasonably established through geophysical methods. Drill stem tests are thus more frequently used than electric logs are run and have, in the past, usually been run whenever there is an indication of a hydrocarbon producing zone. Previous hydrocarbon logs would indicate the apparent production of hydrocarbon gases, and any sudden increase or "gas kick" would suggest the possibility of a hydrocarbon producing zone. However, when previously produced gas is already present in the mud stream, it is sometimes difficult to determine whether a change in the total gas, for instance, is due to new gas in the mud or some other factor. Thus, it is desirable to have a more reliable indicator which will eliminate unnecessary drill stem tests and also suggest others which are actually desirable.

In hydrocarbon well logging, it is unnecessary to remove the drill bit from the well, so that a decided advantage of such logging is the fact that it may be carried out simultaneously with the drilling operation. The depth at which the drill is operating is, of course, determined by the length of the drill string, and this is readily measured and recorded in a known manner. As the drill progresses further down the hole, the time required for the mud to reach the bottom of the hole, as well as flow up the hole, increases. The inside diameter of the drill string is known, so that the time for the mud to proceed from the top of the well to the bit may be calculated from the known volume of mud being pumped down the well. Due to the fact that the formations drilled through do not always retain the borehole size produced by the bit, due to sloughing or caving of softer formations and the size of the bore changes when a smaller bit is used, the time required for the mud or cuttings to proceed from the drill bit to the top of the well is not always proportional to the ratio between the diameter of the drill bit and the inside diameter of the drill string. However, a dye or other type of marker may be placed in the mud stream and timed from its entrance therein to its discharge from the well, then the calculated time for the mud to proceed down the drill stem may be subtracted, in order to arrive at the lag time, i.e., the amount of time representing the difference between the discharge of mud from the bit, including the production of cuttings accompanying the mud, and the time at which this mud and the cuttings carried thereby reaches the surface. Of course, any sloughing or caving will normally occur considerably above the drill bit, so that this factor is not detrimental to the method of this invention, as will hereinafter appear.

In hydrocarbon well logging, e.g., U.S. Patent 2,214,674, a portion of the mud may be treated to remove the occluded gas therein and the gas mixed with air and tested, as by a so-called "hot wire" gas detector, e.g.,

U.S. Patent 2,489,180, for the relative amount of gas therein. Such a hot wire detector has thus been known and used for a number of years, while a more recent development, the gas chromatograph enables the gas to be tested for individual constituents thereof, such as methane, ethane, propane, n-butane, isobutane, n-pentane, isopentane and the like. The gas chromatograph is a highly desirable instrument which provides considerable information, yet operates relatively slowly, so that the gas test can be made on a specimen only at longer intervals of time, such as six minutes apart, whereas the hot wire detector provides substantially instantaneous readings. The gas chromatograph is usually set to provide automatically a test every 10 feet, or perhaps a lesser number of feet, although it can be manually actuated at any time. In addition to testing the mud for gas, samples of the cuttings carried by the mud may be separated therefrom successively and also tested for gas in a known manner, while both the mud and the cuttings may be tested for the presence of oil, as through the observance thereof under ultraviolet light. Also, the cuttings may be subjected to a vacuum, to cause any oil or gas therein to be sucked therefrom and observed under a microscope, e.g., U.S. Patent 2,756,585. The cuttings are also examined to determine the character of the formation from which the cuttings came. All of these tests, of course, increase the knowledge about the formation being drilled through, or actually the formation which was drilled through at the time the well was at the depth indicated by the lag time, which assists the geologist in determining whether a potential oil or gas producing zone has been encountered.

It has been a generally accepted theory for a number of years that the only gas or oil contained in the cuttings comes from the cylinder of the formation chewed up by the bit and that the cuttings lose such gas or oil into the mud, as they proceed up the borehole. It is also a generally accepted theory that, in general, the mud carries the cuttings and the gas it receives up the well in approximately the same order in which the cuttings were produced by the drill bit, although it has been definitely established that the cuttings are not carried upwardly by the mud in precisely the same order in which they were produced from the formation, but that there is a longitudinal intermixing of the cuttings. For instance, if a strata of linestone, with shale both above and below, is drilled through, shale cuttings intermixed with limestone cuttings will be discharged at the top of the well for a period of time after the lag time indicates that the drill is progressing through limestone only. Also, limestone cuttings will appear intermixed with the shale cuttings for a period of time after the drill has passed from the limestone into the shale beneath. This factor is not of considerable importance when the various formations are relatively thick, but when the layers or formations are only a few feet thick, particularly when one of them is a producing formation, such intermixing of the cuttings may be of considerable significance.

Hydrocarbon logs, are, in essence, data sheets giving, for increments of depth of the well, such information as the drilling rate, the lithology as determined by the cuttings, the relative amounts of gas separated from the mud, either determined by the hot wire gas detector or the gas chromatograph, of both, the relative amounts of gas detected upon removal from the cuttings, such as the total gas or gas constituents, and other data, including where drill stem tests were made, where cores were taken, the specific gravity or weight of the mud, the constituents used to make up the mud, and the results of tests of the mud for pH, salinity and the like. When a gas chromatograph is utilized, either the relative amounts of the constituent gases may be plotted in curves, such as one curve for each gas, or the total detection of methan, ethane and propane as one curve, and the total detection of butanes and pentanes, both normal and iso, as another

curve. The significance of these gas curves it that, if there is a sudden increase in the total gas, this is an indication that a formation, from which the mud or cuttings involved came, may be suspected of being an oil or gas producing zone. Also an accompanying sudden increase of the butanes and propanes is indicative of a suspicion that the suspected producing zone may be an oil producing zone.

Notwithstanding the considerable and valuable information which a hydrocarbon well log furnishes the geologist, there are at least two areas in which no procedure heretofore developed has been able to furnish any specific information. The first is the detection of relatively narrow or shallow formations which are possibly oil or gas producing, and the second is a correlation of one or more curves of the hydrocarbon well log with the curves from electrical logging.

Among the objects of this invention are to provide a novel method of hydrocarbon well logging; to provide such a method which provides more accurate information relating to the possibility of an oil or gas producing strata, particularly a narrow or shallow oil or gas producing strata; to provide such a method by which a hydrocarbon well log may be produced which provides additional information to a geologist; to provide such a method which produces a hydrocarbon well log which is more nearly correlated with an electrical log made in the same well; to provide such a method which may be utilized in producing a hydrocarbon well log without requiring the drill bit and drill stem to be removed from the well; to provide such a method which may be carried out simultaneously with the drilling of the well and which thus provides additional information about the formation being drilled through, corresponding to but before an electrical log can be made; to provide such a method which will tend to eliminate unnecessary drill stem tests and suggest those which are actually desirable; and to provide such a method which may be carried out readily and without the necessity of utilizing more than a minimum of additional equipment.

The above and additional objects of this invention, as well as the novel features thereof, will become apparent from the description which follows, when taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a diagram of apparatus used at the drilling site by which the data necessary for carrying out the method of this invention is obtained;

FIG. 2 is a reproduction of a portion of a hydrocarbon log produced in accordance with this invention, covering a depth of 10,420 to 10,600 feet, in a well drilled in Reeves County, Tex.;

FIG. 3 is a reproduction of the portions of three types of electrical logs taken in the same well and between the same depths as in FIG. 2;

FIG. 4 is a reproduction of a portion of a hydrocarbon log produced in accordance with this invention covering a depth of 12,960 feet to 13,040 feet in a well drilled in Martin County, Tex.; and

FIG. 5 is a reproduction of an electrical log of the lateral resistivity type, taken at the same well and between the same depths as in FIG. 4.

Apparatus adapted to carry out the method of this invention, as illustrated in FIG. 1, is utilized with drilling equipment adapted to drill a borehole **10** by means of a drill bit **11**, through various strata or formations, such as stratas of sand **12**, shale **13**, limestone **14** and **15** and conglomerate **16**. The depth of the borehole will, of course, be considerable in comparison with the diameter of the borehole, as indicated by the broken lines between the limestone strata **14** and **15**, the distance between which may be on the order of several thousand feet. The drill bit **11** is attached to the lower end of a drill string **17**, consisting of sections of piping of appropriate length, connected together by joints or collars in the conventional manner. The drill string extends upwardly through a cas-

ing 18 and, above the casing, is rotated by a rotary table 19, just above the rig platform 20. The upper end of the drill string 17 is provided with a swivel joint 21, supported by a hook 22, in turn supported from a conventional drilling rig (not shown). A depth cable 23 is attached to a suitable portion of the supporing structure for hook 22, extends laterally and then downwardly over pulleys, as shown, to a depth meter 24, which may be associated with a recorder, so as to produce a record of the time at which the drill bit was at each increment of depth of the well. Incoming mud is supplied through pipe 25 to the top of swivel joint 21 and is pumped downwardly through the drill string 17, passes out through the drill bit 11 and then moves upwardly within the hole, as indicated by the arrows. From a point adjacent the upper end of casing 18, the outgoing mud flows through an outlet pipe 26 to a slush pit 27. One or more mud pumps 28, whose suction inlets are disposed in a conventional mixing pit for the mud, supplies the mud under the desired pressures to the mud inlet pipe 25.

A portion of the mud is diverted from the outlet pipe 26 through a gas trap diversion pipe 30, for passage to a gas trap 31, in which the mud is agitated by a motor driven stirrer 32, and then passes beneath a baffle, as shown, for discharge through a gas trap outlet pipe 33 into the mud pit 27. In order to shut off the mud diverted to the gas trap 31, when desired, a valve 34 is installed in diversion pipe 30, while a sample pipe 35 provided with a valve 36 is connected to diversion pipe 30. When desired, a mud sample containing a known quantity of specific gases may be suplied to the gas trap, with valve 34 closed and valve 36 open, by feeding the same into sample line intake 37, for calibration or testing of the gas detector and gas chromatograph, referred to below.

It is customary, in installations of this type, to convey the gas separated from the mud in gas trap 31, as through a pipe 38 and through a branch pipe 39 to a hot wire gas detector 40, connected to a recorder 41 by wires 42. Another portion of the gas is conveyed through another branch pipe 43 to a gas chromatograph 44, connected to a recorder 45 by wires 46. At each of hot wire gas detector 40 and gas chromatograph 44, prior to testing, the removed gas is mixed with a predetermined quantity of air, or at any other suitable location between the gas trap 37 and the testing equipment.

The equipment described above is generally conventional for use in hydrocarbon well logging. Additional equipment for use in carrying out the method of this invenion includes a flow meter 50, which is installed in the mud outlet pipe 26 and from which extends a lead wire cable 51 connected to a recorder 52. A flow meter 53 is installed in the gas trap diversion pipe 30, conveniently adjacent gas trap 31, and is connected by a lead wire cable 54 with a recorder 55. Another flow meter 56, installed in the mud inlet pipe 25 and connected by a lead wire cable 57 with a recorder 58, may be utilized in lieu of, or in addition to, the meter 50 installed in the mud outlet pipe 26. The flow meters 50, 53 and 56 may be of any suitable type adapted to measure the flow of mud through the respective pipes, one suitable type being the Halliburton turbine flow meter, which includes a cylindrical flow meter body adapted to be installed at a relatively short section of the pipe and having in the body a rotor provided with blades and mounted on a shaft concentric with the cylindrical body, with longitudinally disposed, radial flow vanes mounted both fore and aft of the rotor, to minimize swirling. The speed of the rotor is proportional to the flow and produces an electrical impulse or signal at a pick-up mounted centrally atop the cylindrical body, these electrical impulses being transmitted through the respective wires to the respective recorders. The recorder charts are, of course, correlated with time and may be set to automatically compensate for the lag time, so that an indication of the flow meter chart for any specific time will correspond with the time at which the drill bit 11 was at a specific depth, as indicated by the depth meter 24 and its associated recorder. Of course, interconnection between the depth meter 24 and the various recorders may be made, so that each chart will have a time and depth correlation.

In accordance with this invention, hydrocarbon well logging is carried beyond the detection and recording of the relative amount of gas contained in the mud diverted from the outgoing flow line, as practiced since 1938 by the use of the hot wire gas detector and refined in recent years by the use of the gas chromatograph, through the following additional steps:

(a) Measuring the total volumetric flow of the mud, preferably the outgoing mud;

(b) Measuring the flow of diverted mud; and

(c) Determining the total relative amount of gas for a selected increment of the well bore, for successive selected increments of depth of the well.

The above method may be further refined by determining the total relative amount of gas for a selected volumetric increment of the well bore, to obtain, rather than a comparative determination which will be definitive for any particular well, a comparative determination which will be definitive for a number of wells and permit comparison thereof. The above step (c) may be carried out by utilizing a chart, as described below, or through utilization of the ratio between the total mud flow and the diverted mud flow, the amount of gas detected per unit volume of mud, determining the amount of gas detected from a selected increment of volume of the total mud flow, then determining the total gas for a selected increment of the borehole, by utilizing the total volume of mud flow for the period during which such selected increment of the hole was drilled. In a refinement of the method, such determination is made more accurate, as for comparison purposes between different wells, by introducing a factor dependent upon the size of the bit and therefore determining the total gas for selected successive volumetric increments of the well drilled. As will be evident, a principal factor utilized in the method of this invention is the total hydrocarbon gas detected, as by the hot wire detector, although in a further refinement of the invention, the amounts of specific gases detected by the gas chromatograph or an equivalent instrument is utilized. Rather than making a determination for each of the gases detected for each increment of the borehole, the total of the lower hydrocarbons methane, ethane and propane, hereinafter sometimes referred to as MEP, and the total of the slightly higher hydrocarbons n-butane, isobutane, n-pentane and isopentane, hereinafter sometimes referred to as BP, may be determined separately. The results of such determinations are preferably plotted on a log as curves, so as to be correlated with the curve indicating the drilling time.

Any suitable system of measurement may be utilized, such as the metric system, although for the United States and other countries in which a similar system is utilized, the drilling rate is conveniently measured in feet per minute, the total mud flow and gas trap diverted mud flow in gallons per minute, the depth of the well in feet, increments of depth of the well in feet and volumetric increments of depth of the well in cubic feet. As will be evident, for sections of the same or several wells drilled with the same size of bit, the final determinations will be directly comparative. However, for different size bits, the determinations should be multiplied by a factor corresponding to the size of the bit, so that the ultimate determinations will be in terms of cubic feet of hole drilled, rather than longitudinal feet of hole drilled. Thus, the multiplication factors for the various sizes of bits will be proportioned to $\pi D^2/4$ or:

For a 6" bit,

$$\frac{\pi D^2}{4} = .1963$$

For an 8" bit,

$$\frac{\pi D^2}{4}=.3491$$

For a 9" bit,

$$\frac{\pi D^2}{4}=.4418$$

For a 10" bit,

$$\frac{\pi D^2}{4}=.5454$$

For a 11" bit,

$$\frac{\pi D^2}{4}=.6600$$

For a 12" bit,

$$\frac{\pi D^2}{4}=.7854$$

For a 14" bit,

$$\frac{\pi D^2}{4}=1.1069$$

For a 24" bit,

$$\frac{\pi D^2}{4}=1.767$$

For a 24" bit,

$$\frac{\pi D^2}{4}=3.1416$$

The method of the present invention is based upon the recognition, apparently not perceived for over 25 years, that the most important factor, which determines the amout of gas that may be detected at the surface, is the amount of mud or drilling fluid that has been circulated through a given foot of drilled hole. In principle, the more mud that has been circulated through the bit while one foot of hole was cut, the greater the dilution of the gas that was introduced into the stream from the foot of formation drilled. The less mud circulated through the given foot of hole will have less dilution and will be more indicative of the formation producibility. The amount of hydrocarbon detected at the surface from the mud stream is directly determined by the amount of mud into which the hydrocarbons have been dispersed or diluted. The drilling rate in minutes per foot times the drilling fluid return in gallons per minute will give the total amount of fluid which circulated by the formation for any given foot of drilled hole. This is the amount of fluid that the hydrocarbons of the drilled foot were dispersed into and is the dilution factor that directly determines the amount of hydrocarbons that will be detected at the surface in the drilling fluid.

Not only does the present method provide a positive correlation of well information from one well to another in the same field or nearby area and allow the operator to compare, in a wildcat well, a new zone encountered with one at a shallower depth in the same well, but also establishes, apparently for the first time, a definite correlation of hydrocarbon mud logs from one logging company to another in nearby locations or areas. Furthermore and quite unexpectedly, hydrocarbon well logs prepared in accordance with the present invention have a definite correlation, in critical areas, with electrical logs taken in the same well at the same depths and therefore are indicative of the results which would be secured if electrical logs were obtained. This is not to suggest that electrical logs can be dispensed with, but only to indicate that significant information, previously secured by electrical logs only, can be obtained through the hydrocarbon well log. One of the significant abilities of such a hydrocarbon well log is an indication of a narrow, possibly producing zone, hitherto difficult, if not impossible, to determine from previous hydrocarbon logs. This is all the more surprising, in view of the tendency for cuttings to migrate from one portion of the mud to another while moving up the bore. However, it is possible, although not definitely established, that the cuttings lose a large proportion of gas to the mud, either adacent the drill bit or within the first few feet, perhaps a hundred or more, above the drill bit. In any event, the most significant characteristic of such hydrocarbon well logs is an indication of an effective hydrocarbon release zone when the curve of total gas per foot of hole or per cubic foot of hole goes opposite to the drilling rate curve, as will be evident from the hydrocarbon well logs illustrated in the drawings.

FIG. 2 is a hydrocarbon well log, prepared in accordance with this invention, for a depth of 10,420 to 10,620 feet, in a well drilled in Reeves County, Tex. It contains, in columns from left to right, the drilling rate curve, the lithology determined from the cuttings, i.e., limestone at the left and shale at the right, with the depth superimposed thereon for convenience, in the center, the total gas curve **60**, i.e., total gas per foot of hole, as a dotted line, a solid line curve **61** based on MEP per foot of hole, another solid line curve **62** based on BP per foot of hole, and a column at the right showing tests of the mud for weight, viscosity, pH, salinity, and other data, such as the appearance of the cuttings. The drilling rate curve and the total gas curve **60** are based on determinations made in accordance with this invention, as in Table I below.

TABLE I

1		2	3	4	5	6	7	8
Depth		Drill Rate, Min./Ft.	Total Mud Flow, G.p.m.	Total Mud, Gal./Ft.	Trap Flow, G.p.m.	Trap Gas, Total	Total, Gas/ Gal.	Total, Gas/ Ft. Hole
From—	To—							
10,420	22	5	500	2,500	10	125	12.5	30,000
	24	7	500	3,500	10	120	12	42,000
	26	10	500	5,000	10	120	12	60,000
	28	10	500	5,000	10	120	12	60,000
10,428	30	7	500	3,500	10	115	11.5	38,500
	32	12	500	6,000	10	400	40	240,000
	34	10	500	5,000	10	175	17.5	85,000
	36	10	500	5,000	10	180	18	90,000
	38	8	500	4,000	10	160	16	64,000
10,438	40	12	500	6,000	10	160	16	96,000
	42	9	500	4,500	10	120	12	48,000
	44	12	500	6,000	10	120	12	72,000
	46	10	500	5,000	10	120	12	60,000
	48	7	500	3,500	10	120	12	42,000

TABLE I—Continued

1		2	3	4	5	6	7	8
Depth		Drill Rate, Min./Ft.	Total Mud Flow, G.p.m.	Total Mud, Gal./Ft.	Trap Flow, G.p.m.	Trap Gas, Total	Total, Gas/ Gal.	Total, Gas/ Ft. Hole
From—	To—							
10,448	50	12	500	6,000	10	120	12	72,000
	52	12	500	6,000	10	120	12	72,000
	54	8	500	4,000	10	120	12	48,000
	56	7	500	3,500	10	160	16	56,000
	58	12	500	6,000	10	180	18	108,000
10,458	60	8	500	4,000	10	160	16	64,000
	62	8	500	4,000	10	120	12	48,000
	64	4	500	2,000	10	120	12	24,000
	66	8	500	4,000	10	120	12	48,000
	68	5	500	2,500	10	120	12	30,000
10,468	70	9	500	4,500	10	160	16	72,000
	72	8	500	4,000	10	160	16	64,000
	74	5	500	2,500	10	160	16	40,000
	76	6	500	3,000	10	160	16	48,000
	78	8	500	4,000	10	180	18	72,000
10,478	80	10	500	5,000	10	160	16	80,000
	82	9	500	4,500	10	160	16	72,000
	84	5	500	2,500	10	160	16	40,000
	86	12	500	6,000	10	160	16	96,000
	88	9	500	4,500	10	160	16	72,000
10,488	90	7	500	3,500	10	160	16	56,000
	92	5	500	2,500	10	160	16	40,000
	94	11	500	5,500	10	70	7	38,500
	96	9	500	4,500	10	65	6.5	27,000
	98	8	500	4,000	10	80	8	32,000
10,498	500	13	500	6,500	10	85	8.5	52,000
	02	16	500	5,000	10	100	10	50,000
	04	13	500	6,500	10	115	11.5	71,500
	06	9	500	4,500	10	115	11.5	49,500
	08	8	500	4,000	10	120	12	48,000
10,508	10	5	500	2,500	10	550	55	137,500
	12	3	500	1,500	10	160	16	24,000
	14	4	500	2,000	10	180	18	36,000
	16	7	500	3,500	10	180	18	63,000
	18	7	500	3,500	10	180	18	63,000
10,518	20	2	500	1,000	10	180	18	18,000
	22	3	500	1,500	10	185	18.5	27,000
	24	3	500	1,500	10	185	18.5	27,000
	26	3	500	1,500	10	185	18.5	27,000
	28	4.5	500	2,250	10	190	19	42,750
10,528	30	3.5	500	1,750	10	190	19	33,250
	32	3.5	500	1,750	10	185	18.5	31,500
	34	3.5	500	1,750	10	185	18.5	31,500
	36	2	500	1,000	10	185	18.5	18,000
	38	2	500	1,000	10	160	16	16,000
10,538	40	2.5	500	1,250	10	160	16	16,000
	42	4	500	2,000	10	280	28	56,000
	44	3.5	500	1,750	10	560	56	98,000
	46	4	500	2,000	10	400	40	80,000
	48	4.5	500	2,250	10	480	48	98,400
10,548	50	5	500	2,500	10	480	48	120,000
	52	4	500	2,000	10	480	48	96,000
	54	5.5	500	2,550	10	480	48	122,400
	56	2	500	1,000	10	480	48	48,000
	58	4.5	500	2,050	10	480	48	98,400
10,558	60	2.5	500	1,050	10	480	48	50,400
	62	3	500	1,500	10	400	40	72,000
	64	4	500	2,000	10	448	44.8	88,000
	66	8	500	4,000	10	448	44.8	176,000
	68	3	500	1,500	10	448	44.8	66,000
10,568	70	5	500	2,500	10	400	40	100,000
	72	4.5	500	2,050	10	400	40	82,000
	74	4	500	2,000	10	400	40	80,000
	76	4	500	2,000	10	400	40	80,000
	78	4.5	500	2,050	10	320	32	65,600
10,578	80	3	500	1,500	10	320	32	48,000
	82	7	500	3,500	10	280	28	98,000
	84	7	500	3,500	10	240	24	84,000
	86	5	500	2,500	10	240	24	60,000
	88	8	500	4,000	10	240	24	96,000
10,588	90	9	500	4,500	10	260	26	117,000
	92	6	500	3,000	10	280	28	84,000
	94	6	500	3,000	10	320	32	96,000
	96	11	500	5,500	10	560	56	308,000
	98	7	500	3,500	10	560	56	196,000
	10,600	4	500	2,000	10	560	56	112,000

In the above Table I, the figures in column 4 are the product of the figures of columns 2 and 3, column 7 is the figures of column 6 divided by the figures of column 5, and column 8 is the product of the figures of columns 4 and 7, each for the corresponding depth. As will be noted, the figures of column 8 are plotted as the total gas curve **60**. Curves **61** and **62** of FIG. 2 are plotted from the additional determinations in Table II below.

TABLE II

1		9	10	11	12	13	14
Depth		MEP	MEP/ Gal.	MEP/Ft. Hole	BP	BP/ Gal.	BP/Ft. Hole
From—	To—						
10,422	24	.73	.073	255	.04	.004	14
10,428	30	.52	.052	182	.1	.010	35
10,434	36	3.39	.339	1,695	.07	.007	35
10,438	40	.71	.071	426	.02	.002	12
10,446	48	.85	.085	297	.07	.007	24
10,456	58	.54	.054	324	.04	.004	24
10,466	68	.45	.045	112	.04	.004	10
10,478	80	.99	.099	495	.09	.009	45
10,488	90	.99	.099	346	.09	.009	31
10,504	06	.78	.078	351	.08	.008	36
10,508	10	4.44	.444	1,110	.41	.041	102
10,528	30	1.22	.122	213	.07	.007	12
10,538	40	2.15	.215	225	.43	.043	45
10,546	48	5.70	.570	1,168	.24	.024	49
10,552	54	5.50	.550	1,402	.19	.019	48
10,578	80	3.09	.309	463	.28	.028	42
10,590	92	2.40	.240	720	.27	.027	81
10,598	00	7.20	.720	1,440	.69	.069	138
10,604	06	5.30	.530	1,855	.56	.056	196
10,612	14	5.60	.560	1,120	.57	.057	114

In the above Table II, the figures in column 9, MEP, are the totals of methane, ethane and propane detected by the gas chromatograph, while the figures in column 12, i.e. BP, are the totals of n-butane, isobutane, n-pentane and isopentane, also detected by the gas chromatograph. As will be evident, the readings of the gas chromatograph are not obtained as frequently as those of the hot wire gas detector, so that Table II does not contain data for as many specific feet of depth of the hole as does Table I. In Table II, columns 10 and 13 are the figures of columns 9 and 12, respectively, divided by the figures of column 5 of Table I, while columns 11 and 14 are the product of figures of columns 10 and 13, respectively, and column 4 of Table I. As will be evident, the figures of column 11 are plotted as the MEP curve **62** of FIG. 2, while the figures of column 14 are plotted as the BP curve **61** of FIG. 2, but to different scales, that for curve **61** being the 0 to 800 scale and for curve **62** being the 0 to 200 scale. It will also be noted that the total gas curve **60** is plotted on the 0 to 200 scale, but multiplied by 1,000, and that the total gas trap readings of column 6 of Table I are on a different scale from the MEP and BP readings of columns 12 and 10, respectively, of Table II. These different scales do not affect the results secured, since the significant aspects of these curves is the curve direction, including increases and decreases, and particularly when compared with the drilling rate curve. As will be evident, the determinations made in accordance with this invention may be plotted as curves or points of curves on a hydrocarbon well log, as in FIG. 3, for correlation with the drilling rate curve or points of a curve, thereby correlating the same with the drilling rate.

On the log shown in FIG. 2, there are several indications of zones, possibly productive of hydrocarbons, albeit gas producing zones. Thus, the arrows **63** through **73** and the oppositely directed arrows adjacent the drilling rate curve, indicate positions at which the total gas curve extends in the opposite direction from the drilling rate curve at depths of 10,428 ft., 10,433 ft., 10,458 ft. 10,474 ft., 10,483 ft., 10,489 ft., 10,516 ft., 10,544 ft., 10,552 ft., 10,554 ft., and 10,558 ft., respectively. When this factor is combined with a marked increase in MEP curve **61** at 10,433 ft., i.e., arrow **64**, and between 10,540 ft. and 10,560 ft., i.e., arrows **70–73**, the zone is indicated to be a possibly gas producing zone. It will be noted that the BP curve **62** does not have any sudden increases as does the MEP curve **61**, although when a possibly oil productive zone is encountered, the BP curve **62** should show a marked increase. It will be noted that the total gas curve **60** goes off the chart at 10,434 ft. and also at 10,596 ft., as will be evident from Table I, while the MEP curve **61** goes off the chart between 10,546 ft. and 10,566 ft., as will be evident from Table II.

Referring now to FIG. 3, which, from left to right, contains a lateral log, gamma ray log and sonic log, made in the same well for the same depth as in FIG. 2, it will be noted that a gamma ray log delineates the type of formation and corresponds generally to the drilling rate curve, while the sonic log gives an indication of porosity. Quite unexpectedly, the curve **60** of total gas per foot of hole of FIG. 2, corresponds generally to the sonic electric log of FIG. 3. Also, it will be noted that the arrows **63** to **73**, inclusive, of FIG. 3, directed toward various points on the sonic log, and corresponding arrows directed toward the gamma ray log, indicate positions at which the sonic log and the gamma ray log extend in opposite directions. As will be noted, arrows **63** to **73** of FIG. 3 are at approximately the same depths as arrows **63** to **73** of FIG. 2. A lateral log, as in FIG. 3, corresponds generally to the gamma ray log, but gives a better indication of breaks between different formations, such as between shale and limestone, or vice versa. However, the peaks and valleys of the lateral log extend in the opposite direction to the peaks and valleys of the gamma ray log, so that the gamma ray log is more readily compared with the sonic log, to determine points or areas in which the curves extend in opposite directions.

FIG. 4 is the drilling rate curve and the total gas detected per cubic foot of mud, for a depth of 12,960 ft. to 13,040 ft. in a well drilled in Martin County, Tex. The total gas curve of FIG. 4 is based upon a determination made in accordance with this invention, as shown in Table III below, in which columns 1 through 8 have the same meaning as in Table I, except that column 8 represents total gas per cubic foot of hole, rather than longitudinal foot of hole, with a 6 inch bit.

TABLE III

1		2	3	4	5	6	7	8
Depth		Drill Rate, Min./Ft.	Total Mud Flow, G.p.m.	Total Mud, Gal./Ft.	Trap Flow, G.p.m.	Trap Gas, Total	Total, Gas/ Gal.	Total Gas/Cu. Ft. Hole
From—	To—							
12,950	952	10	500	5,000	10	100	10	50,000
	54	6.5	500	3,000	10	120	12	36,000
	56	7	500	3,500	10	116	11	38,500
	58	14	500	7,000	10	120	12	84,000
	960	7.5	500	3,500	10	120	12	42,000
	62	6.5	500	3,000	10	110	10	30,000
	64	7	500	3,500	10	120	12	42,000
	66	4	500	2,000	10	130	13	26,000
	68	5	500	2,500	10	140	14	35,000
	970	7	500	3,500	10	130	13	45,500
	72	7.5	500	3,500	10	130	13	45,500
	74	4	500	2,000	10	200	20	40,000
	76	6.5	500	3,000	10	180	18	54,000
	78	5	500	2,500	10	180	18	45,000
	980	4.5	500	2,000	10	200	20	40,000
	82	5.5	500	2,500	10	200	20	50,000
	84	5	500	2,500	10	180	18	45,000
	86	5	500	2,500	10	160	16	40,000
	88	7.5	500	3,500	10	150	15	52,500

TABLE III—Continued

1		2	3	4	5	6	7	8
Depth		Drill Rate, Min./Ft.	Total Mud Flow, G.p.m.	Total Mud, Gal./Ft.	Trap Flow, G.p.m.	Trap Gas, Total	Total, Gas/ Gal.	Total, Gas/ Ft. Hole
From—	To—							
	990	6.5	500	3,000	10	130	13	39,000
	92	5.5	500	2,500	10	140	14	35,000
	94	7	500	3,500	10	130	13	45,500
	96	5.5	500	2,500	10	150	15	37,500
	98	5	500	2,500	10	160	16	40,000
13,000	----------	5	500	2,500	10	150	15	37,500
	02	4	500	2,000	10	160	16	32,000
	04	3	500	1,500	10	220	22	33,000
	06	3	500	1,500	10	180	18	27,000
	08	3	500	1,500	10	140	14	21,000
13,008	10	3	500	1,500	10	164	16	24,000
	12	3	500	1,500	10	150	15	22,500
	14	3	500	1,500	10	164	16	24,000
	16	3	500	1,500	10	168	16	24,000
	18	7.5	500	3,500	10	164	16	56,000
	20	10	500	5,000	10	142	14	70,000
	22	11	500	5,000	10	138	13	65,000
	24	4	500	2,000	10	158	15	30,000
	26	7.5	500	3,500	10	128	12	42,000
	28	6.5	500	3,000	10	200	20	60,000
	30	6	500	3,000	10	125	12	36,000
	32	6.5	500	3,000	10	168	16	48,000
	34	12	500	6,000	10	168	16	96,000
	36	7	500	3,500	10	160	16	56,000
	38	8.5	500	4,000	10	40	4	16,000
13,040		9.5	500	4,500	10	200	20	90,000

The total gas per cubic foot of hole, or total gas per foot of hole, may also be determined through use of a chart, such as the chart entitled, "Nomograph for Hydrocarbon Well Logging," by Olan T. Moore.

As will be evident, at the points on FIG. 4 indicated by arrows **85** through **90** and oppositely directed arrows at corresponding positions adjacent the drilling rate curve, the total gas curve extends in the opposite direction at depths of about 12,977 ft., 12,998 ft. 13,004 ft., 13,010 ft., 13,027 ft. and 13,032 ft. Also, the relatively wide variations on the total gas curve, including the positions at arrows **86**, **87** and **88**, as compared with the relative steadiness of the drilling rate, indicate that the entire area from 12,997 ft. to 13,010 ft. may be a producing zone. However, the variations in the drilling rate in that general area indicate that at arrow **85**, there may be a narrow producing zone, while a broader but still relatively narrow producing zone is indicated at the position of arrows **89** and **90**. A resistivity microlog is recorded with electrodes which are mounted a relatively short distance apart on an insulating pad which is pressed against the wall of the drill hole. It is used primarily to determine the permeable beds in those areas where hard or well consolidated formations are predominant. In the resistivity microlog of FIG. 5, the points or curve portions to the right are indicative of a tightness or greater density of the formation, while the points or curve portions to the left are indicative of porosity or lesser density of the formation. The formation through which the well of FIGS. 4 and 5 was drilled, between the depths indicated, was a fairly tight limestone, as determined by lithology (not shown). On the resistivity microlog of FIG. 5, taken in the same well at the same depths as FIG. 4, the points **92**, **93**, **94** and **97** correspond to the position of arrows **85**, **86**, **87** and **90**. The broad point **95** corroborates that the producing zone may extend to 13,020 ft., while the broad point **96** is quite close to arrow **89**. A producing oil well is now in operation by the setting of casing and perforations over the area corresponding to arrows **86** to **90** of FIG. 4.

In the above, it has been assumed that the total mud flow will vary from time to time, even though the amount of diverted mud may remain substantially constant, and that therefore a factor dependent upon the variations in the total flow of mud should be considered. However, there are numerous wells in which the total mud flow remains substantially constant over long periods of time, with the diverted mud flow also remaining substantially constant. Thus, it will be noted that, in each of Table I and Table III, both the total mud flow and the diverted mud remain constant, for the portion of the depth of the well indicated in these charts. The determination of the total gas per foot of hole may be expressed by the following formula:

$$\text{Drilling time (ft./min.)} \times \frac{\text{Total mud flow (g.p.m.)}}{\text{Trap flow (g.p.m.)}} \times \text{Gas reading} = \text{Gas per ft. hole}$$

When changes in bit size are to be considered and a factor corresponding to a conversion of the borehole in feet to cubic feet is introduced, the above formula may be expressed as follows:

$$\text{Drilling time (ft./min.)} \times \frac{\text{Total mud flow (g.p.m.)}}{\text{Trap flow (g.p.m.)}} \times \frac{\text{Gas reading}}{\text{Hole conversion (ft. to cu. ft.)}} = \text{Gas per cu. ft. hole}$$

As will be evident from each of the above formulae, if the total mud flow and the trap flow remain constant, then, for the first formula above, the product of the drilling time and the gas reading will reflect any variations in the gas per linear foot of hole, while if the hole conversion factor, i.e. bit size, also remains constant, then the product of the drilling time and the gas reading will again reflect any variations in the total gas per cubic foot of hole.

In view of the fact that numerous wells are drilled during long periods over which the total mud flow remains constant, the relative amount of gas per foot of hole or per cubic foot of hole may be determined, in a relative manner, by utilizing the product of the total gas reading and the drilling time. Of course, the relative amount of MEP per foot or cubic foot of hole, as well as the relative amount of BP per foot or cubic foot of hole, is also desirably determined. For comparison between various holes, a factor corresponding to the total mud flow divided by the diverted mud may be introduced. For a number of wells drilled in an area, it is common to use the same size of bit down to or between the same depths in each borehole. Thus, when a comparison is to be made with another well which has a similar or identical bit program, then it is unnecessary

to consider variations in the diameter of the hole, due to the bit size. Of course, if any well is to be compared with another well which does not or did not have the same bit program, then factors corresponding to the bit size should be introduced.

Although a preferred embodiment of apparatus adapted to be utilized in carrying out the method of this invention has been illustrated and described, it will be understood that numerous other types of equipment may exist. Also, it will be understood that variations, changes and modifications may be made in the method of this invention without departing from the spirit and scope thereof.

What is claimed is:

1. A hydrocarbon well logging method for a well drilled by a bit through successive formations, wherein:

a mud is passed downwardly from the well site to the bit and then upwardly to the surface and, in passing upwardly, carries with it cuttings produced by the action of the bit and hydrocarbon gases passing from the cuttings into the mud and any hydrocarbon gases seeping into the mud from a formation drilled through;

a portion of the mud discharged at the well site is diverted and gases are separated from the diverted mud;

the depth of the well is measured in increments and the rate of drilling is also measured; and

the gas separated from the diverted mud is tested for the total relative amount of a selected number of hydrocarbon gases, said method comprising, in addition:

measuring the total flow rate of mud;

measuring the flow rate of diverted mud; and

correlatively recording, for successive selected increments of depth of the well, the total relative amount of gas for the mud flowing through increments of the well bore at such depths, whereby to obtain the relative gas content of each volumetric increment of the formation through which the well is drilled.

2. A method of hydrocarbon well logging, as defined in claim 1, wherein:

the outgoing total flow of mud is measured.

3. A method of hydrocarbon well logging, as defined in claim 1, wherein:

the incoming total flow of mud is measured.

4. A method of hydrocarbon well logging, as defined in claim 1, wherein:

said hydrocarbon gases detected include methane, ethane, propane, n-butane, isobutane, n-propane and isopropane.

5. A method of hydrocarbon well logging, as defined in claim 4, including:

determining, for said successive selected increments of depth of the well, the relative amount of the total of methane, ethane and propane detected for said selected increments of the well bore at such depths; and

separately correlatively recording for said successive selected increments of depth of the well, the relative amount of the total of n-butane, isobutane, n-pentane and isopentane for said selected increments of the well bore at such depths.

6. A method of hydrocarbon well logging, as defined in claim 1, including:

determining, for successive increments of the well drilled, the volume of the formation drilled through;

determining, for successive increments of the well drilled, the amount of such hydrocarbon gas detected for a selected volumetric increment of the total mud flow; and

correlatively recording therefrom said hydrocarbon gas detected for the total and mud flowing through selected successive volumetric increments of the well.

7. A method as defined in claim 1, including correlating said drilling rate with said determination of the relative amount of detected gas for said selected volumetric increment of well drilled.

References Cited

UNITED STATES PATENTS

2,214,674	9/1940	Hayward	73—153
2,280,075	4/1942	Hayward	73—153 X
2,341,169	2/1944	Wilson et al.	73—153
2,528,882	11/1950	Hayward	73—153
3,069,895	12/1962	Burk	73—23.1

JAMES J. GILL, *Primary Examiner.*

RICHARD C. QUEISSER, *Examiner.*

JERRY W. MYRACLE, *Assistant Examiner.*