May 28, 1946. J. E. WALSTROM 2,401,280

METHOD FOR LOCATING PERMEABLE FORMATIONS TRAVERSED BY A BORE HOLE

Filed June 18, 1942 2 Sheets-Sheet 1

Fig: 1.

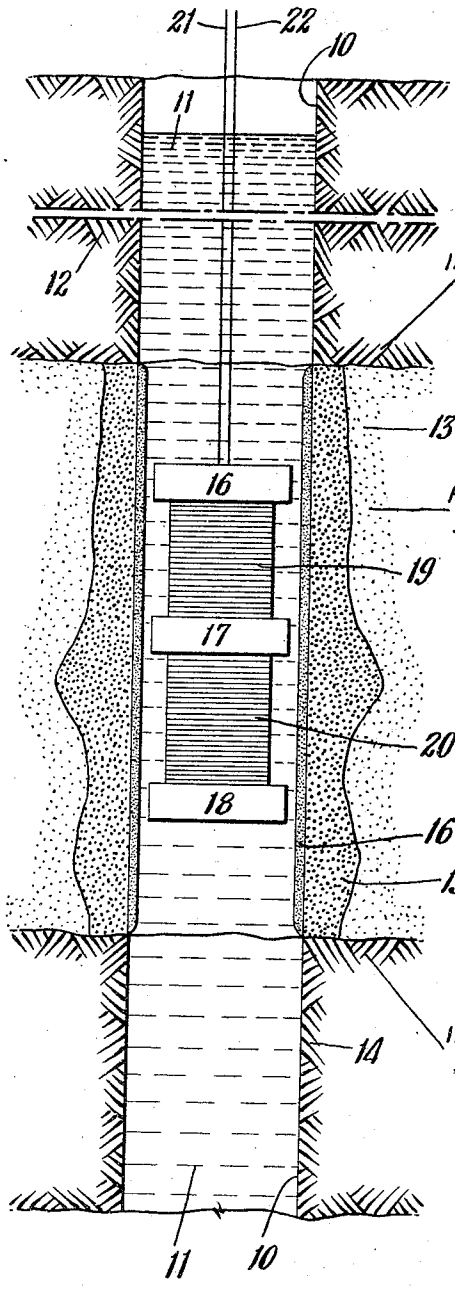

Fig: 2.

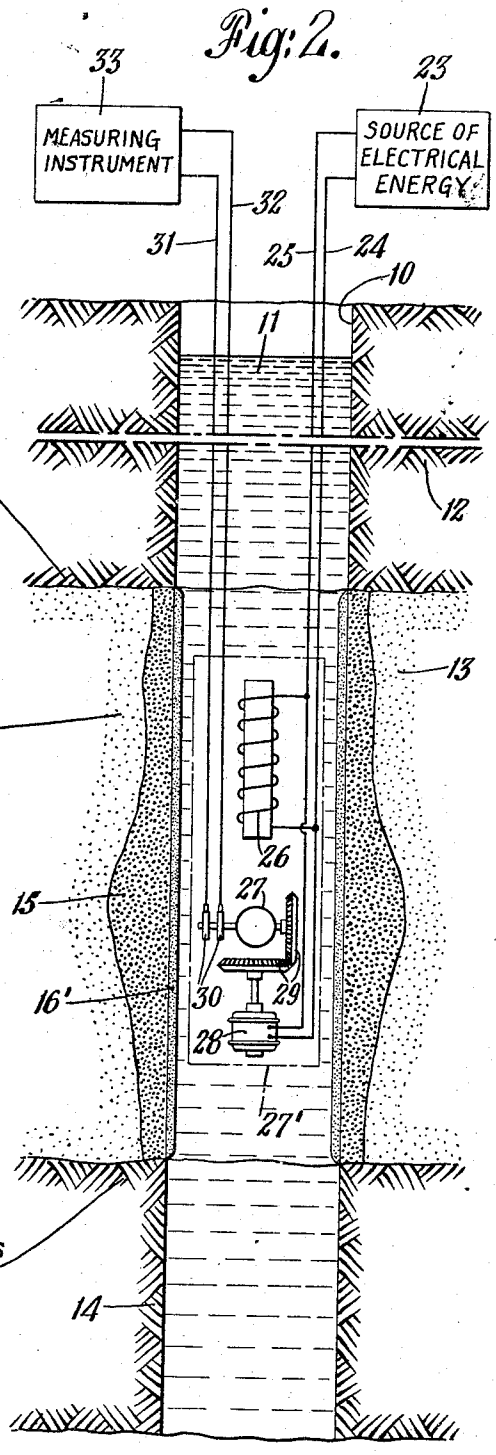

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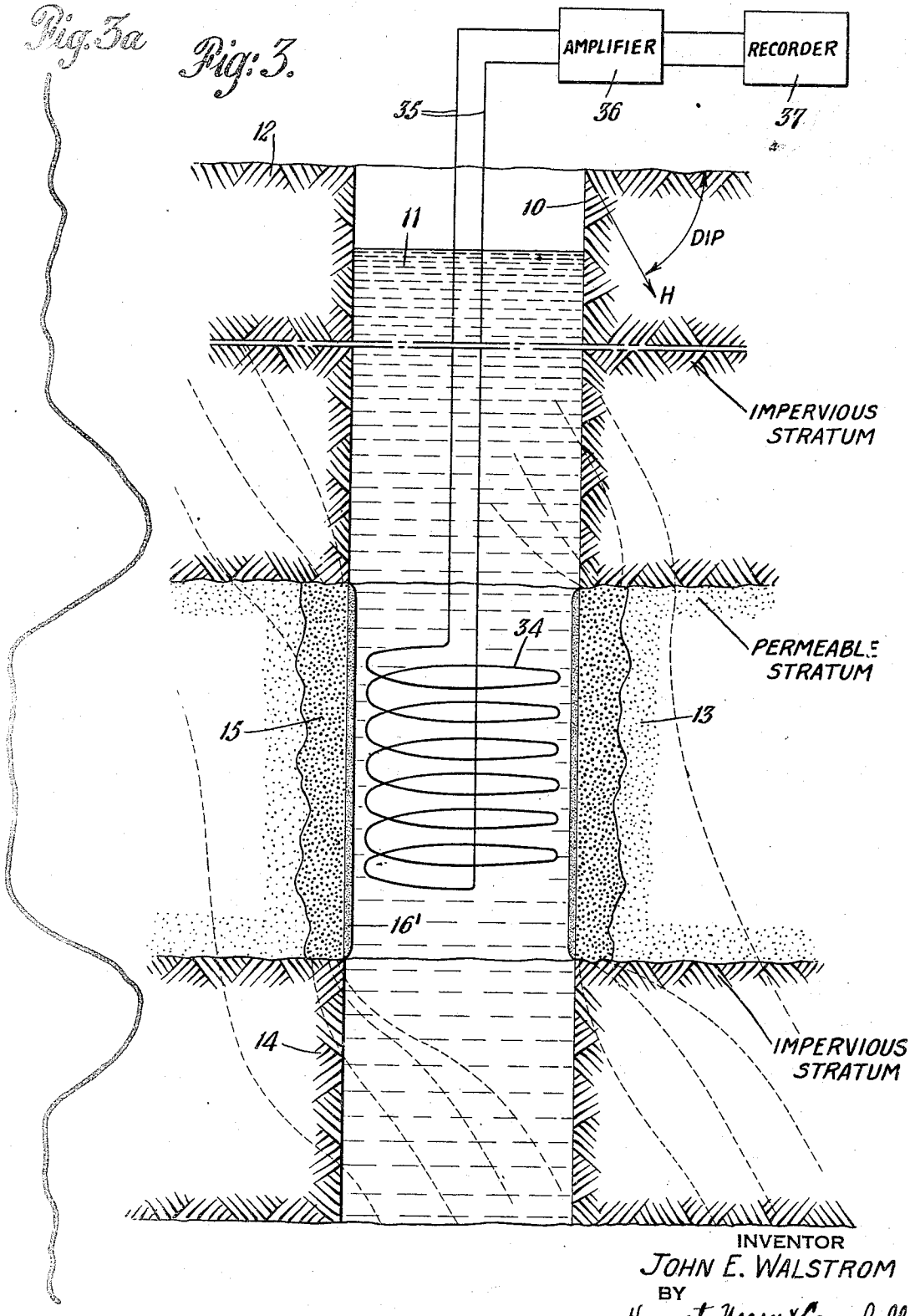
Fig. 3a

Fig. 3.



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Patented May 28, 1946 2,401,280

UNITED STATES PATENT OFFICE

2,401,280

METHOD FOR LOCATING PERMEABLE FORMATIONS TRAVERSED BY BOREHOLES

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Application June 18, 1942, Serial No. 447,504

6 Claims. (Cl. 175—182)

The present invention relates to methods for locating the depths and boundaries of permeable formations traversed by a bore hole drilled into the earth.

More specifically, it relates to a method of the above character in which permeable formations may be located by investigating the mud cake which tends to form on the wall of a bore hole containing a column of drilling fluid in the vicinity of such formations.

In drilling wells by the rotary method, good engineering practice requires that the hole be filled with a drilling fluid, the density of which is controlled so that the hydrostatic pressure at any depth in the drill hole is greater than the natural formation pressure at that depth. This condition tends to prevent the walls of the hole from caving and prevents a formation from "blowing out" which would occur if the formation pressure exceeded the borehole pressure. By virtue of its viscosity and movement, this drilling fluid further serves to carry the cuttings from the drill bit to the surface of the earth.

In general, the drilling fluid comprises a colloidal system of finely pulverized solids in suspension in a liquid, usually water or sometimes oil. The solids employed are of a great variety and are generally chosen according to the influence that they have on the weight, viscosity and/or plastering qualities of the drilling fluid. Inasmuch as the pressure in the permeable formations is less than the hydrostatic pressure exerted by the column of drilling fluid, the latter tends to invade such formations to a certain extent. During the course of such invasion, some of the solid material suspended in the drilling fluid may be carried a short distance into the formations.

The greater part of the solid material in the invading fluid, however, tends to accumulate on the wall of the bore hole at the levels of the permeable formations. The accumulated solid material forms a "cake," the thickness of which is a function of the permeability of the formation and the difference in pressure between the drilling fluid and any fluid in the formation. This "cake" serves a useful function in that it limits the extent of invasion of the permeable formations by the drilling fluid.

It is an object of the invention to provide a novel method for locating the depth and thickness of permeable formations by investigating the "cake" formed by the drilling fluid on the walls of a bore hole in the vicinity of permeable formations in which the fluid pressure is less than the hydrostatic pressure of the drilling fluid.

Another object of the invention is to provide a novel method of the above character in which a "cake" is formed on the wall of the bore hole in the vicinity of permeable formations, which "cake" is of such character that its presence may be readily located by means lowered into the bore hole from the surface of the earth.

A still further object of the invention is to provide a method of the above character in which a magnetic substance is added to the drilling fluid and indications are obtained of magnetic phenomena related to the presence of the magnetic substance in the "cake" or in the formations adjacent the bore hole.

A further object of the invention is to provide a method for producing in the vicinity of permeable formations a "cake" having magnetic properties, whereby its location may be readily detected.

Still another object of the invention is to provide a novel method of the above character in which a magnetic substance is introduced into the drilling fluid whereby the "cake" formed on the wall of the bore hole at the levels of permeable formations will have magnetic properties, thereby facilitating its detection.

A still further object of the invention is to provide a novel method of the above character in which a "cake" having magnetic properties is formed on the wall of the bore hole at the levels of permeable formations traversed by a bore hole, the location of which "cake" is determined by observing its influence on a magnetic field in the bore hole.

The objects of the invention are attained by introducing into the drilling fluid a substance of such character that the permeable formations and the "cake" formed on the wall of the bore hole in the vicinity thereof have distinguishing properties that can readily be detected by means lowered into the bore hole from the surface of the earth.

The substance introduced into the drilling fluid may be one which imparts magnetic properties to the mud cake and the permeable formations, for example. In such cases, the levels at which the mud cake exists may be determined by investigating a magnetic property of the formations at different depths in the bore hole. The magnetic property will be more pronounced wherever a "cake" exists on the wall of the bore hole, than elsewhere, so that the depth and thickness of the "cake" can be readily determined. From this information, the depth and thickness of the permeable formation with which the cake is associated can be readily ascertained.

The invention may be better understood from the following detailed description of several representative embodiments, taken in conjunction with the accompanying drawings, in which:

Figure 1 is a schematic diagram illustrating one embodiment of the invention in which the locations of permeable formations treated with a magnetic substance are determined by obtaining indications of the magnetic retentivity of the materials surrounding the bore hole;

Figure 2 is a schematic diagram illustrating another embodiment of the invention in which indications are obtained of the magnetic permeability of the materials comprising the wall of the bore hole;

Figure 3 is a view in longitudinal section through a portion of a bore hole illustrating a further embodiment of the invention in which the earth's magnetic field is employed for locating permeable strata in accordance with the invention, and

Figure 3a is a typical log of a well, produced in accordance with the present invention.

Referring now to Figure 1, a bore hole 10 is shown containing a column of liquid 11 and traversing an impervious formation 12, a permeable formation 13 and a second impervious formation 14. It will be assumed in the following description that the pressure of any fluid contained in the permeable formation 13 is less than the hydrostatic pressure of the drilling fluid 11 so that the latter has invaded a substantially cylindrical layer 15 of the formation 13. As a result of this invasion, some of the solid material suspended in the drilling fluid 11 has accumulated on the wall of the bore hole 10 in the vicinity of the permeable formation 13, forming a "cake" 16' which, in practice, may vary from $\frac{1}{32}$ to ½ inch or more in thickness.

In accordance with the invention, a substance is introduced into the drilling fluid 11 which is of such character that the "cake" 16' formed in the vicinity of the permeable formation 13 has distinguishing properties that can be readily detected. Preferably this is accomplished by introducing into the drilling fluid 11 a substance having ferromagnetic or paramagnetic properties.

The substance may comprise a solution which may be thoroughly mixed with the drilling fluid 11 by circulation through the drill stem in the conventional manner or by "spotting" with a conventional type bailer. If the substance to be used is not soluble in the drilling fluid 11, it may be finely pulverized prior to being introduced into the drilling fluid 11 so that it will, for all practical purposes, remain sufficiently in a suspended state during the process of circulation and until it finally becomes a fixed and integral part of the "cake" or formation.

Whether the substance is soluble or insoluble in the drilling fluid, the filtering action of the permeable formation 13 will cause part of the addition agent added to the drilling fluid 11 to form part of the cake 16' coating the wall of the bore hole 10 in the vicinity of the permeable formation 13. In this fashion the "cake" on the wall of the bore hole 10 at the level of each permeable formation in which the fluid pressure is less than the hydrostatic pressure of the drilling fluid 11 will have marked magnetic properties which will enable it to be readily distinguished from other formations traversed by the drill hole 10.

Other impervious formations such as the formations 12 and 14, for example, may retain a small quantity of the addition agent but it will have little effect upon the magnetic properties of such impervious formations so that it may be neglected.

A number of different substances may be used as addition agents in accordance with the method. Ferromagnetic materials, such as for example, iron powder or magnetite are entirely satisfactory and paramagnetic substances, such as for example ferric chloride, may also be employed with good results. Some of the ingredients customarily used in making drilling fluids employed in drilling operations, particularly the so-called weight materials, such as "Colox" and "Baroid" contain magnetic substances that may be availed of in accordance with the method. A typical example of such a satisfactory material is "Colox" which contains ferric oxide, a magnetic substance, and a gel-forming colloid for keeping the ferric oxide in suspension in the drilling fluid. Where such drilling fluids are used, it may not be necessary to supply an addition agent to the drilling fluid in the practice of the method.

Although it is not essential, the substance should preferably be added to the drilling fluid during the drilling operations. The substances thus added will be deposited along the walls of the hole opposite the permeable formations in which the fluid pressure is less than the hydrostatic pressure of the drilling fluid and will become part of the cake. The location of the cake may be determined by investigating a magnetic property of the materials surrounding the bore hole at different depths therein. In order to increase the accuracy of the method, the bore hole 10 might be flushed out with clean mud not containing any of the addition agent, although it is not necessary to do this.

After the cake has been formed in the vicinity of permeable formations, in the manner described above, it may be located by means of any suitable apparatus for investigating a magnetic property of the wall of a bore hole or of the formations traversed thereby. Suitable apparatus for this purpose is disclosed in prior Patent No. 2,259,904, for example, and need not be described in detail herein. As indicated in Figure 1, the apparatus comprises three longitudinally spaced apart pole pieces 16, 17 and 18, between which are disposed the windings 19 and 20 which are connected in series opposition.

The series connected coils 19 and 20 are adapted to be energized from a source of electrical energy located at the surface of the earth through the conductors 21 and 22 in the supporting cable (not shown). As disclosed in the above mentioned prior patent, the polarity of the current supplied to the windings 19 and 20 is automatically reversed each time the apparatus has moved a distance approximately equal to the spacing between the pole pieces 16 and 17. Thus, after the apparatus has been lowered from the top to the bottom of the bore hole, a continuous series of alternate north and south poles will exist along the length of the bore hole, the strength of which will be the function of the magnetic properties comprising the materials of the wall of the bore hole.

As indicated above, wherever a cake having magnetic properties has been formed in the wall of the bore hole 10, the strength of the magnetic poles will be much greater than the magnetic poles existing in the vicinity of impervious formations.

When the magnetizing apparatus has reached the bottom of the bore hole 10, it is disconnected from the source of current and is connected to suitable indicating means, preferably located at the surface of the earth. The apparatus, which then acts as a pick-up device, is raised in the bore hole, causing the windings 19 and 20 to cut the lines of force comprising the magnetic field, creating a voltage which is measured by the indicating means at the surface of the earth. Zones of high magnetic retentivity will then be indicated as waves of large amplitude upon the record obtained at the surface of the earth. These zones of high magnetic retentivity correspond to the locations of the cakes which are formed in the vicinity of permeable formations in the manner as indicated above.

Instead of investigating the magnetic retentivity of the materials comprising the wall of the bore hole, indications may be obtained of the magnetic permeability of such materials in accordance with the method disclosed in Figure 2. In this embodiment, a magnetic field is created by moving a magnetizing element along the length of the bore hole and indications are obtained of the variations in the resultant field. If the magnetic field of the magnetizer and the spatial relation between it and the pick-up means are held constant, the variations in the field picked up will be due to variations in the magnetic permeability of the intervening strata. Large variations will be observed adjacent the permeable formations which have retained relatively large amounts of ferromagnetic or paramagnetic material.

Referring to Figure 2, electrical energy is supplied from a source 23 located at the surface of the earth through the conductors 24 and 25 to a solenoid 26 mounted in a substantially fluid-tight non-magnetic casing 27' disposed in the bore hole 10. The solenoid 26 when energized creates a magnetic field in the cake 16', the invaded zone 15 and in the surrounding formations adjacent the bore hole 10. Disposed a fixed distance beneath the solenoid 26 is a pick-up coil 27 which is adapted to be rapidly rotated in the magnetic field created by the solenoid 26. To this end it is driven by motor 28 through conventional gearing 29.

The potential induced in the pick-up coil 27 is transmitted through conventional type slip rings 30 or through a commutator, if desired, and through the conductors 31 and 32, to a suitable indicating instrument 33, preferably of the recording type, located at the surface of the earth. Preferably the spacing between the solenoid 26 and the pick-up coil 27 should be less than the thickness of the strata to be investigated. Similar apparatus suitable for this purpose is disclosed in prior Patents Nos. 2,220,788 and 2,259,904.

In the embodiment illustrated in Figure 3 of the drawings, the "cake" having magnetic properties is located by observing its influence upon the earth's magnetic field in the bore hole. In this case, a magnetic material, such as, for example, iron powder, has been added to the drilling fluid and the iron particles have become concentrated adjacent the permeable formation 13, forming a cake 16' having magnetic properties as described above.

Provided the friction in the cake 16' is not too great, small groups of the iron particles in the cake 16' will, to a certain extent, align themselves more or less in the direction of the earth's magnetic field in that vicinity. In most of the regions of interest, the dip of the earth's magnetic field is such that its vertical component is the predominant one. Accordingly, groups of the iron particles will orient themselves, according to the dip of the field, and will constitute a long, tubular, magnet, the length of which will be equal to the thickness of the permeable stratum 13.

The presence of the magnet constituted by the cake 16' distorts the earth's magnetic field and causes a crowding of the lines of force at the upper and lower extremities of the formation 13, as indicated in the drawing. If a suitable investigating device, such as for example a simple solenoid 34 having its axis parallel to and approximately coincident with the axis of the bore hole is lowered through the bore hole 10, voltage will be induced therein whenever it passes the upper and lower boundaries of a permeable formation 13.

At those boundaries, the solenoid 34 cuts magnetic lines of force, inducing a voltage therein, which may be transmitted to the surface of the earth through the conductors 35 and amplified by a conventional type amplifier 36 before being fed to a suitable indicating device 37, preferably of the recording type to produce a log such as that shown in Figure 3a, the depths therealong corresponding to the depths of the formations shown in Figure 3. While the solenoid 34 is moved between the upper and lower boundaries of the formation 13, only a small voltage will be recorded by the recorder 37, so that the only outstanding deflections on the record will correspond to the boundaries between dissimilar formations at the zones wherein the flux density changes.

From the foregoing it is apparent that the invention enables permeable formations traversed by a drill hole to be easily and accurately located. By introducing into the drilling fluid a material of such character that a cake having magnetic properties is formed in the wall of the bore hole in the vicinity of permeable formations in which the fluid pressure is less than the hydrostatic pressure of the drilling fluid, the presence of the cake may be readily determined and from it the depth and thickness of permeable formations easily deduced.

It will be understood that any of the above described measurements or determinations may be conducted before any magnetic material is introduced into the bore hole and the measurements repeated after the addition of the magnetic material. By following this procedure, a still more accurate determination may be made in accordance with the invention.

The several specific apparatuses described above for creating an artificial magnetic field in the bore hole and for obtaining indications of the magnetic field in the bore hole are given merely as illustrative. Any other suitable devices may be used for this purpose within the skill of the art.

While several specific embodiments have been described above, the invention is not intended to be in any way limited thereby but is susceptible of numerous changes in form and detail within the scope of the following claims.

I claim:

1. A process for locating permeable formations traversed by an uncased bore hole containing a column of liquid, comprising adding to the bore hole liquid a substance having magnetic properties whose presence can be readily detected, maintaining a sufficiently high hydrostatic pressure in

the bore hole to cause said liquid to invade permeable formations traversed by said bore hole and deposit at said permeable formations a higher concentration of said substance than at other zones along said bore hole, and moving along said bore hole a device for detecting magnetic phenomena to locate the formations having such higher concentrations of said substance.

2. A process for locating permeable formations traversed by an uncased bore hole containing a column of liquid having solid materials suspended therein, comprising adding to the bore hole liquid a substance having magnetic properties, maintaining a sufficiently high hydrostatic pressure in said bore hole to cause the liquid to penetrate into permeable formations, allowing the bore hole liquid to remain in the bore hole a sufficient length of time to form a cake in the vicinity of said formations, in which cake the concentration of the added substance is greater than it is in the vicinity of other formations, and passing along said bore hole a detecting device responsive to variations in magnetic flux to detect said cake and supply an indication of the presence of said cake.

3. A process for locating permeable formations traversed by an uncased bore hole containing a column of liquid having solid materials suspended therein, comprising adding to the bore hole liquid a substance having magnetic properties, maintaining a sufficiently high hydrostatic pressure in said bore hole to cause the liquid to penetrate into the permeable formations, allowing the bore hole liquid to remain in the bore hole a sufficient length of time to form a cake in the vicinity of said formations, in which cake the concentration of the added substance is greater than it is in the vicinity of other formations, passing along the bore hole a device for creating a magnetic field, energizing said device and alternately reversing its polarity as it passes along said bore hole to create in the formations a series of alternate north and south poles, the strength of which will be a function of the magnetic properties of the formations and the cake, and passing a detecting device responsive to variation in magnetic flux along said bore hole to detect and supply an indication of the presence of the cake.

4. A process for locating permeable formations traversed by an uncased bore hole containing a column of liquid, comprising adding to the bore hole liquid a substance having magnetic properties, maintaining the hydrostatic pressure of the liquid sufficiently high to cause it to penetrate into the permeable formations, leaving the liquid in the bore hole for a sufficient period to produce a relatively high concentration of said substance in the vicinity of the permeable formations, magnetizing the materials comprising the wall of the bore hole and moving along said bore hole a detecting device responsive to variation in magnetic flux to obtain indications of the magnetic retentivity of said materials.

5. A process for locating permeable formations traversed by an uncased bore hole containing a column of liquid, comprising adding to the bore hole liquid a substance having magnetic properties, maintaining the hydrostatic pressure of the liquid sufficiently high to cause it to penetrate into said permeable formations, leaving the liquid in the bore hole for a sufficient period to produce a relatively high concentration of said substance in the vicinity of the permeable formations, influencing the materials comprising the wall of the bore hole with a magnetic field, and moving along said bore hole a detecting device responsive to variation in magnetic flux to obtain indications of the resultant magnetic field in the bore hole.

6. A process for locating permeable formations traversed by an uncased bore hole containing a column of liquid, comprising adding to the bore hole liquid a substance having magnetic properties, maintaining the hydrostatic pressure of the liquid sufficiently high to cause it to penetrate into said permeable formations, leaving the liquid in the bore hole for a sufficient period to produce a relatively high concentration of said substance in the vicinity of the permeable formations, and moving along said bore hole a detecting device responsive to variation in magnetic flux to obtain indications of the variations in the magnetic flux in the bore hole produced by the distortion of the earth's magnetic field by the magnetic substance in the vicinity of the permeable formations.

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