United States Patent [19]

Fertl et al.

[11] **3,722,606**

[45] **Mar. 27, 1973**

[54] DETECTING ABNORMAL FORMATION PRESSURE DURING DRILLING OF A WELL

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[22] Filed: **Aug. 16, 1971**

[21] Appl. No.: **171,902**

[52] **U.S. Cl.** **175/41,** 175/50, 73/153

[51] **Int. Cl.** **E21b 47/00**

[58] **Field of Search**.....175/40, 41, 50, 65, 66; 73/152, 153

[56] **References Cited**

UNITED STATES PATENTS

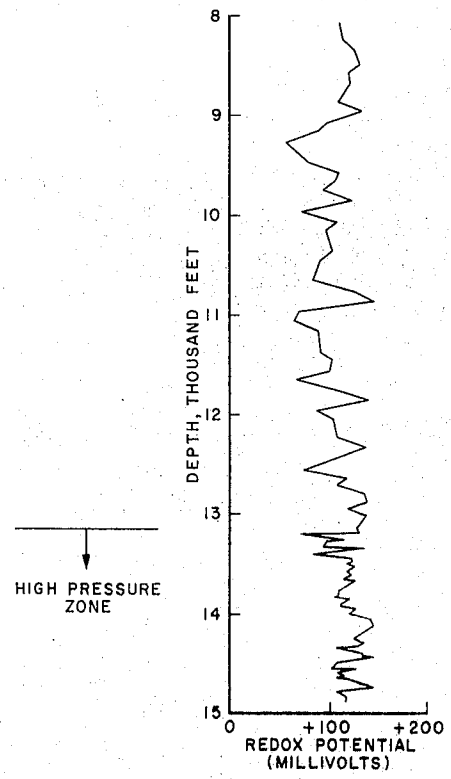
2,454,952	11/1948	Starkey et al.	175/50 X
3,237,094	2/1966	Blackburn et al.	175/50 X
3,382,933	5/1968	Hottman	175/50
3,409,092	11/1968	Doremus	175/50
3,670,829	6/1972	Overton	73/152

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[57] **ABSTRACT**

An early warning detection method for predicting abnormal formation pressure in subterranean rock strata before it is drilled. The technique is to measure, on a sample removed from the well bore, the tendency of an atomic particle to escape from the environment, such as the pH or redox potential, while the well is being drilled, in the normally pressured rock strata existing above the abnormally pressured formations. When variations are observed in the rate of change of escape tendency with depth, drilling procedures are altered to meet the requirements of the formation which is about to be penetrated by the drill bit.

8 Claims, 2 Drawing Figures



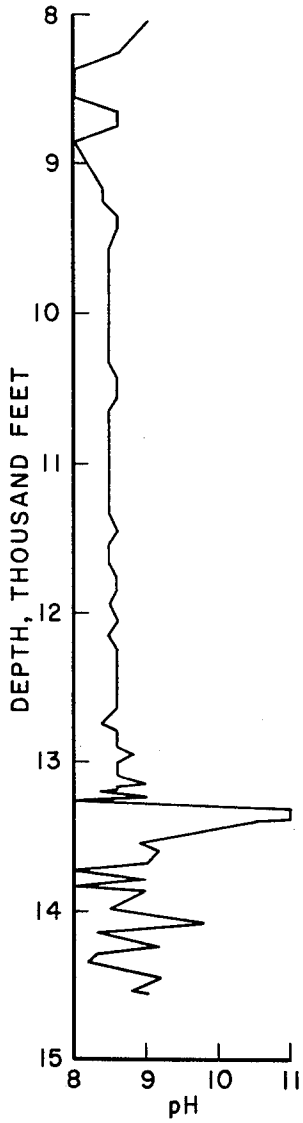
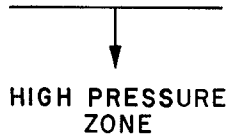

8
9
10
11
12
13
14
15
DEPTH, THOUSAND FEET
8
9
10
11
pH

FIG. 1


HIGH PRESSURE
ZONE

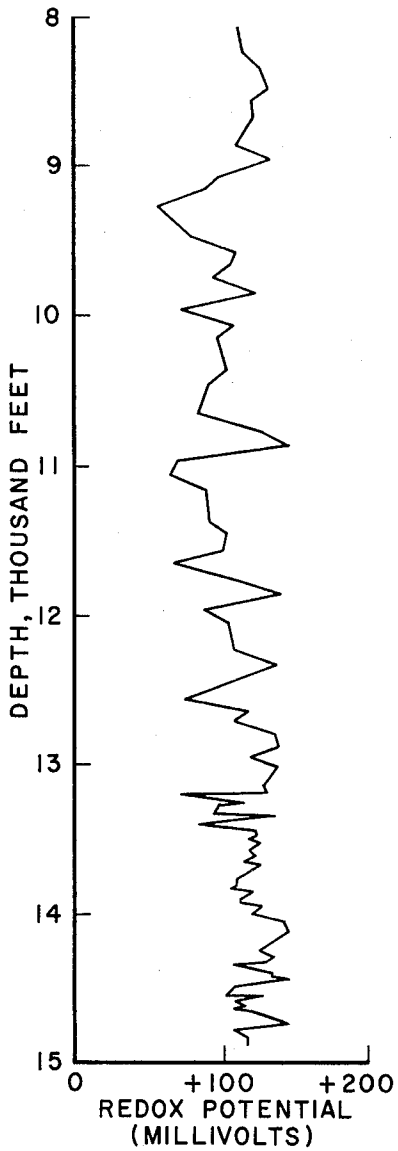

8
9
10
11
12
13
14
15
DEPTH, THOUSAND FEET
0
+100
+200
REDOX POTENTIAL
(MILLIVOLTS)

FIG. 2

DETECTING ABNORMAL FORMATION PRESSURE DURING DRILLING OF A WELL

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention involves a method of monitoring the tendency of an atomic particle to escape from the environment of a sample removed from the well bore as a well is drilling through subsurface rock formations containing zones having normal and abnormal formation fluid pressures. More particularly, the invention involves the detection and prediction of impending pressure changes well ahead of the drill bit, i.e., 200 to 1,500 feet prior to actually drilling the pressure changes. This forewarning of impending pressure changes is vital since engineering preparations can be instigated to drill the well safely and efficiently through the pressure change to the desired depth. Other pressure detection systems presently in use in the drilling industry do not assure this prediction of formation pressure changes not yet drilled.

2. Description of the Prior Art

When a well is drilled, normal pressures, i.e., hydrostatic pressures, exist to some unknown depth where abnormal pressures might be encountered. In the normally pressured zones, formation pressure increases at a constant rate with increasing depth. This rate of increase is approximately 0.465 pounds per square inch per foot of depth, and is the equivalent to the pressure exerted at the base of a column of water containing 80,000 ppm total solids. Abnormal pressures either are less than (under-pressured) or greater than (geopressured) this pressure gradient of 0.465 psi/ft.

In many geographical areas, such as the Gulf Coast of the United States, abnormal pressures are encountered. Of particular importance are geopressures since these are very common and can cause very severe drilling problems. When geopressures are encountered, they must be drilled with a weighted drilling fluid that exerts a pressure exceeding that of the geopressured zone or else the shale and fluids in the abnormal pressured zone, i.e., oil, gas, and/or water, will flow into the well bore and possibly cause a catestrophic "blowout." Numerous causes for geopressures have been postulated. One such cause is that shales and sands that are being buried deeper because of additional deposition on top must compact to stay at normal pressure. These shales and sands can only compact, however, if the associated water is allowed to leak off. If this water cannot bleed off, the formations will exhibit geopressures i.e., high fluid pressures.

Underpressures, although much less frequently encountered compared to geopressures, have been found in areas of oil and/or gas production where pressure in the formations is depleted through the years by production.

In drilling wells in any formation pressure environment, the weight of the drilling mud is balanced against the pressure of the formation being drilled. The fastest and most efficient drilling rates are obtained when an overbalance of mud to formation pressure is held to a minimum. The penetration rate begins to decrease dramatically when overbalances exceed about 300 psi more than formation pressures at 10,000 to 12,000 feet. This is only about 0.5 pound/gal. mud weight excess. Further it is dangerous to drill with mud weight

pressures that exceed formation pressures by about 1,000 psi which is about 2.0 pounds/gal. mud weight excess at 10,000 to 12,000 feet since this high a differential pressure can cause the formations to fracture or break down with loss of the mud column into the formation. When mud is lost in one zone, the entire mud column drops decreasing the hydrostatic mud head and overbalance across some zones and even probably getting into an underbalanced condition across these other zones. When this happens, the differential pressure of higher formation pressure than mud pressure will allow flow of formation fluid into the well bore. This can literally cause the entire mud column to be blown out of the hole resulting in a catastrophic blowout and loss of the hole, drilling rig, and endangering the lives of the rig personnel.

Also when mud weight pressure to formation pressure is excessive as when overbalance exceeds about 1,000 psi, there is a tendency for the drill pipe to stick due to this differential pressure. To get unstuck sometimes can be so expensive or even impossible with present technology that the well has to be abandoned with great financial loss.

It can be seen that the drilling of wells through abnormal pressures requires great engineering skill. The knowledge of impending abnormal pressures enables the drilling engineer to prepare and perform the drilling in a safe and efficient engineering manner, since he is aware of the impending difficulties and problems.

Present methods used in pressure detection such as wire line logs, i.e., electric, acoustic, density, all require temporarily suspending drilling operations to acquire the logs. Further, wire line logs must be considered as after-the-fact since they have the inherent drawback that the abnormal pressures can only be detected after the zone has been drilled. In many instances, getting pressure information at this time is too late as drilling problems such as pipe sticking and well blowouts occur when the abnormal pressure zones are being penetrated.

Other methods of abnormal pressure detection while drilling include bulk density measurements of the drilled shale cuttings, drill penetration rate, torque or drag on the drill pipe, mud pump pressure, mud pit level changes, measurement of gas in mud system and clay mineral changes. These methods for pressure detection are generally faster than the wire line logging techniques, but they all have the same drawback in that the abnormal pressure zone must be penetrated before it can be detected.

The drilling industry is in need of a method for predicting and detecting abnormal pressure zones prior to drilling into them. It is an object of this invention to provide a method of predicting and detecting pressure changes before drilling them. It is another object to drill geopressured formations without danger of a blowout. It is also an object of this invention to keep mud weights at a minimum during drilling so that loss of circulation does not occur. It is a further object to drill abnormal pressured formations at a high penetration rate without ceasing drilling operations to detect such abnormal pressures. Other objects, advantages and features of this invention, will become obvious from the following specification and appended claims.

SUMMARY OF THE INVENTION

This invention involves a method of drilling a well through subsurface rock strata containing abnormal formation pressures at some unknown depth. The normally pressured (hydrostatic pressured) portions of the strata are drilled according to well known techniques in which a drilling fluid is circulated in the borehole. While drilling the normally pressured rock, the drilling fluid is maintained at a relatively low weight, i.e., balanced against or slightly above hydrostatic pressure, so that fast and economic drilling can be accomplished. During this drilling operation samples are periodically taken of materials being circulated out of the borehole. These samples may be drilling mud, cores or cuttings removed from the well at various depth intervals. The tendency of atomic particles to escape from the environment is then determined on these samples. In the normally pressured formations the rate of change of escape tendency with depth is relatively constant. However, several hundred feet above a geopressured interval the rate of change alters sharply. When this occurs, it is a signal that a geopressured zone lies somewhat below the drill bit in yet undrilled rock strata. Thus, this early warning of impending geopressure permits the drilling engineers to start controlled drilling procedures. These procedures, such as keeping a constant rotary speed and weight on the bit while monitoring penetration rate, will alert the driller when the geopressure is reached since the penetration rate will begin to increase under these controlled procedures at this time and the geopressures will not be masked by uncontrolled conditions. The weight of drilling fluid can then be adjusted to compensate for the change in formation pressure. Drilling a well in the above described method provides the fastest and most efficient drilling, but most important permits the safest drilling. Controlled drilling procedures require special precautions which makes their use throughout the entire drilling operation technically difficult and uneconomical.

BRIEF DESCRIPTION OF THE DRAWING

FIGS. 1 and 2 are plots of measurements of pH and redox potentials made on cuttings from a well being drilled.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The drilling fluid used in this process may be an aqueous or oil base drilling mud, air or mist. Where a drilling mud is used, the pressure of the column of drilling mud against the formation is increased by increasing the density of the drilling mud as by adding to the mud barium sulfate or some other weighting agent. If air or mist drilling is being employed, the pressure is increased by increasing the amount of air being compressed.

Subterranean strata exhibit a wide variety of chemical factors the magnitude of which varies with depth. Among such chemical factors is the tendency of an atomic particle to escape from the environment such as the acidity-alkalinity (pH) involving the escape of a proton or the oxidation-reduction potential (redox potential, Eh) of a system involving the escape of an electron. These chemical factors appear to depend on the environment when the strata were laid down and whether the environment was modified by the migration and accumulation of fluids. It has been found that when the rate of change of pH or Eh with depth changes sharply, an underlying geopressured zone is indicated.

pH is defined as the negative logarithm to the base 10 of the hydrogen ion activity of a solution. The pH can be determined by using a color change indicator such as phenolphthalein, methyl orange or a sulphonephthalein (for example bromothymol blue). The pH can also be determined electrically by use of a pH meter which consists of an electrode reversible to hydrogen ions. The electrode is dipped into a test solution and connected by means of a saturated potassium chloride salt bridge with a standard half-cell, usually the saturated calomel electrode via a potentiometer. Common electrodes reversible to hydrogen ions include the hydrogen gas electrode, the quinhydrone electrode, the antimony electrode and the glass electrode. Numerous apparatus and methods, such as those mentioned above, are well known for determining the pH of a fluid and any such apparatus or method may be used in connection with this invention.

Many systems contain a substance in two oxidation states in equilibrium with each other.

Reduced State $\leftrightharpoons$ Oxidized State $+ n$ Electrons The potential of such a system is given by the general equation:

$$Eh = Eo - (RT/nF) \text{ in (Oxidized State)/(Reduced State)}$$

where n is the number of electrons difference between the two states; Eh is the potential measured with respect to the hydrogen electrode or redox potential; Eo is the standard oxidation-reduction potential, R is the universal gas constant; F is the Faraday's constant and T is the absolute temperature of the system and the parenthetical expression is the molar concentration of the substance. The redox potential, Eh, can be measured by a two electrode system. Typically, two electrode systems are a platinum indicator electrode and a saturated calomel, glass or silver-silver chloride reference electrode, preferably with a salt bridge. Suitable apparatus and methods, such as those mentioned above, are well known for determining Eh and any such apparatus or method may be used in connection with this invention.

WELL EXAMPLES

To demonstrate the effectiveness of the method of this invention pH and redox potential measurements were made on shale cuttings at the well site during drilling of offshore Louisiana test well number 2. Shale cuttings were periodically removed from the aqueous drilling mud stream circulated out of the well during drilling. The cuttings were washed to remove drilling mud and screened to remove both coarse cave-ins and fines, such as sand and recirculated small cuttings. The washed cuttings were placed in a blender along with about four parts by weight of distilled water per part by weight cuttings and blended for 2 minutes to form a slurry. The pH of the slurry was determined using a pH meter having a glass electrode in combination with a

calomel reference electrode. The redox potential of the slurry was measured between a calomel electrode and an inert platinum electrode using an ion meter. Both the pH and redox potential values were recorded on a two-pen strip chart recorder. FIG. 1 is a plot of pH versus depth over the depth interval of from 8,000 to 15,000 feet. FIG. 2 is a plot of redox potential in millivolts versus depth over the same depth interval.

Referring to FIG. 1, the pH values varied from 8 to 8.6 from 8,000 to about 13,100 feet. Just below 13,100 feet the pH began to vary more than at lesser depths and at 13,280 feet jumped to 11 after being at 8 at 13,260 feet. At still lower depths the pH continued to vary considerably and at higher values than at lesser depths. Thus the approach of a high pressure zone was indicated. The weight of the drilling mud was then increased in accordance with well known procedures to match this high pressure.

Referring to FIG. 2, the redox potential over the interval 8,000 feet to 13,100 feet varied from about 70 to about 200 millivolts. Over the interval from 12,500 to 13,100 feet there was a gradual increase in the redox potential. Just below 13,100 feet the redox potential dropped sharply indicating the approach of a high pressure. Thus the redox potential confirmed the trend showed by the pH.

The foregoing discussion and description have been made in connection with preferred specific embodiments of the process for detecting abnormal pressure zones during drilling of a well. However, it is to be understood that the discussion and description of the invention is only intended to illustrate and teach those skilled in the art how to practice the process and is not to unduly limit the scope of the invention which is defined and claimed hereafter. For example in addition to making redox and pH measurements on the slurry made from shale cuttings, such measurements may be made on slurries made from formation samples taken with a sidewall cutting apparatus. Alternatively any slurry may be filtered and measurements made on the resulting filtrate. Further measurements may be made on samples of the drilling fluid stream being circulated into or out of the borehole. Measurements may be made by periodically sampling a portion of the material being circulated out of the borehole, or, as in the case of testing the drilling fluid, continuously with the results conveniently being plotted on a strip chart recorder connected to the measuring apparatus.

In the claims:

1. A method for detecting the approach of an underlying abnormally pressured zone while drilling normally pressured zones of a subterranean strata comprising:

a. drilling the normally pressured zones with a drilling fluid whose pressure is balanced against the subterranean strata pressure,

b. monitoring the tendency of an atomic particle to escape from a sample of the subterranean strata being drilled,

c. when the rate of change of tendency of such an atomic particle to escape with depth begins to change greatly, instituting controlled drilling procedures, and

d. when the abnormally pressured zone is penetrated, adjusting the drilling fluid pressure to balance the same against the pressure in the abnormally pressured zone.

2. The method of claim 1 wherein the tendency of an atomic particle to escape is measured by determining the pH of a sample of said subterranean strata.

3. The method of claim 1 wherein the tendency of an atomic particle to escape is measured by determining the redox potential of a sample of said subterranean strata.

4. The method of claim 1 wherein the controlled drilling procedures instituted comprise keeping a constant rotary speed and weight on the bit while monitoring the penetration rate.

5. A method for detecting the approach of an underlying geopressure zone while drilling normally pressured subterranean strata comprising:

a. drilling the normally pressured subterranean strata with a drilling fluid whose pressure against the subterranean strata is balanced against pressure in the subterranean strata,

b. monitoring the tendency of an atomic particle to escape from a sample of the subterranean strata being drilled,

c. when the tendency of such an atomic particle to escape begins to decrease, instituting controlled drilling procedures, and

d. when the controlled drilling procedures indicate that a geopressured zone has been penetrated, adjusting the drilling fluid pressure to balance the same against the pressure in the geopressured zone.

6. The method of claim 5 wherein the tendency of an atomic particle to escape is measured by determining the redox potential of a sample of said subterranean strata.

7. The method of claim 5 wherein the tendency of an atomic particle to escape is measured by determining the pH of a sample of said subterranean strata.

8. The method of claim 6 wherein the controlled drilling procedures instituted comprise keeping a constant rotary speed and weight on the bit while monitoring the penetration rate.

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