

[54] **PREDICTING OCCURRENCE OF
GEOPRESSURED SUBTERRANEAN ZONES
DURING DRILLING**

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175/65**

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[58] Field of Search **73/152, 153;
166/250; 175/44, 46, 50, 65**

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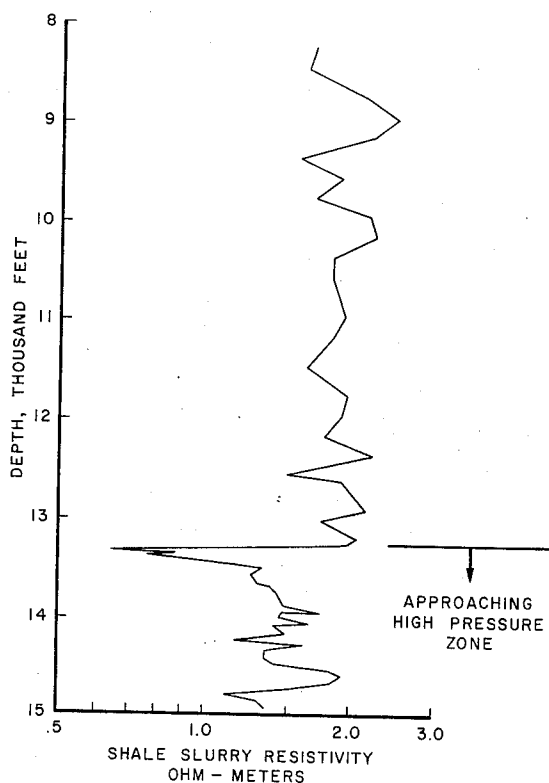
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[57] **ABSTRACT**

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 an electrical characteristic such as the resistivity or its reciprocal, conductivity, preferably corrected for formation temperature, while the well is being drilled, in the normally pressured rock strata existing above the abnormally pressured formations. When variations are observed in the degree of change of resistivity or conductivity 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, 3 Drawing Figures



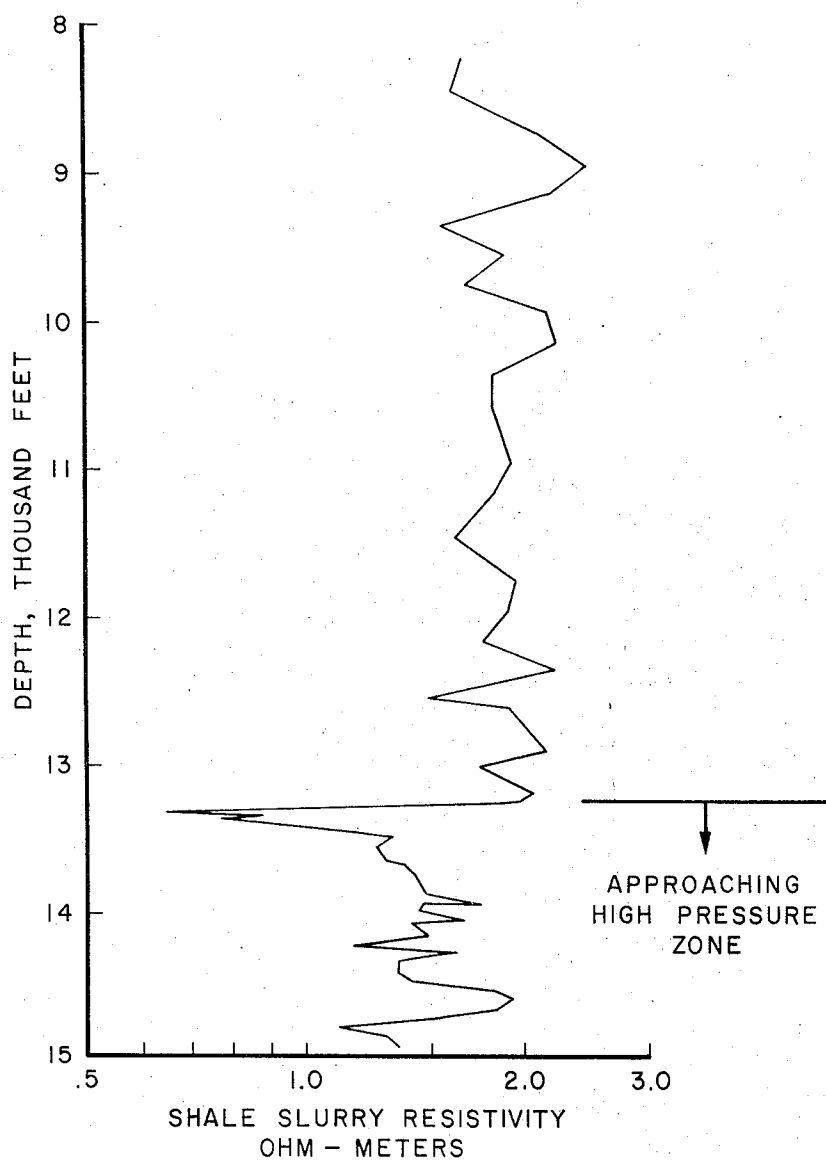


FIG. 1

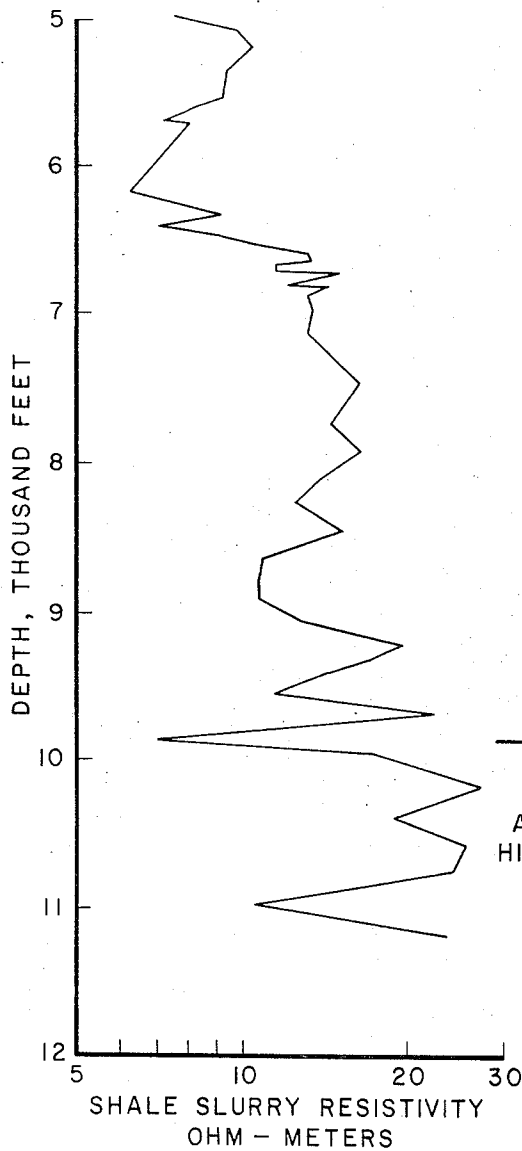


FIG. 2

APPROACHING
HIGH PRESSURE
ZONE

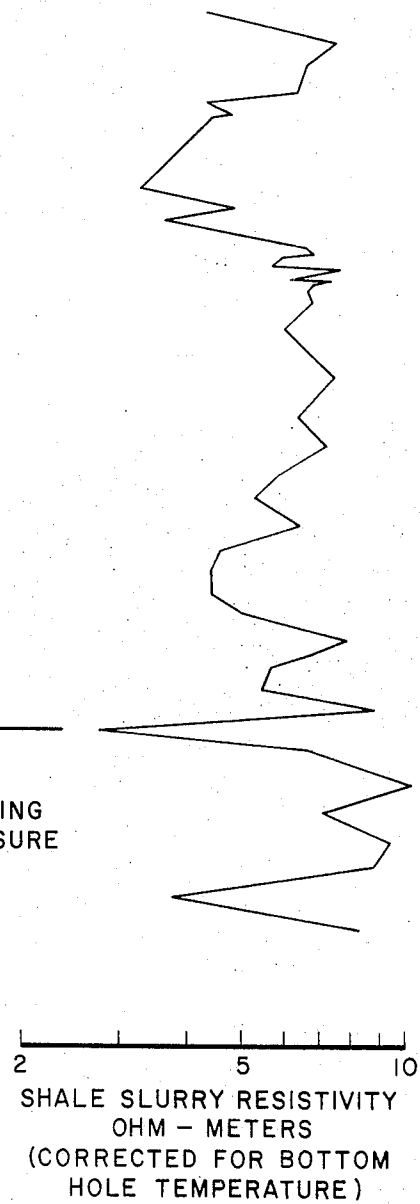


FIG. 3

PREDICTING OCCURRENCE OF GEOPRESSURED SUBTERRANEAN ZONES DURING DRILLING

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention involves a method of indirectly determining changes in the bottomhole pressure 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 1500 feet prior to actually drilling the pressure changes. This forewarning of impending pressure changes is vital so that engineering preparations can be altered for successfully drilling 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 a guaranteed 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 transition to 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 of the pressure exerted at the base of a column of water containing 80,000 ppm total solids. Abnormal pressures either are less than (underpressured) 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 catastrophic "blowout" or drill string sticking. 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.

Drilling wells in any formation pressure environment requires the weight of the drilling mud to be 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. excess mud weight. Further it is dangerous to drill with mud weight pressures that exceed formation pressures by

about 1000 psi which is about 2.0 pounds/gal. excess mud weight 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 1000 psi, there is a tendency for the drill pipe to stick due to this differential pressure. To get unstuck sometimes can be very expensive or even impossible with present technology; thus 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 none of these guarantee the ahead-of-bit prediction in all cases.

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 safe 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 pressures) 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. An electrical characteristic, such as resistivity or its reciprocal quantity, conductivity, is then determined on these samples. In the normally pressured formations the rate of change of resistivity or conductivity is relatively constant. However, several hundred feet above a geopressed interval the rate of change alters sharply. When this occurs, it is a signal that a geopressed 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 DRAWINGS

FIGS. 1, 2 and 3 are plots of resistivity measurements made on cuttings from a well being drilled versus depth.

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 properties the magnitude of which varies with depth. Among these properties are electrical characteristics, such as the resistivity or conductivity of the strata. These properties 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 resistivity or conductivity with depth changes sharply, an underlying geopressed zone is indicated.

Resistivity or conductivity can conveniently be measured using a conductivity bridge or any other apparatus well known in the art. For comparative purposes, it

is preferred to correct resistivity readings to a common temperature. In examples 1 and 2 presented below resistivities were corrected to a temperature of 80°F before being plotted.

Making a plot of resistivity versus depth enables the operator drilling a well to more easily see the sudden change in rate of change of resistivity with depth characteristic of the approach to a high pressure zone. Often this change can be further emphasized by correcting the resistivity for the formation temperature of the sample whose resistivity is being measured. The temperature of the formation is calculated as follows:

$$T_F = T_m + (T_g \times D/100)$$

where

T_F = formation temperature

T_m = mean surface temperature

T_g = temperature gradient, about 1.4°F/100 feet

D = depth in feet.

All temperature measurements are in degrees Fahrenheit.

The corrected resistivity at the formation temperature is calculated by the following equation:

$$R_{T_F} = R_s \times T_s/T_F$$

where

R_{T_F} = resistivity at the temperature of the formation

R_s = resistivity at surface temperature

T_s = temperature at the surface

T_F = temperature of the formation.

A comparison of FIG. 2, wherein resistivity values were corrected to 80°F, with FIG. 3, wherein resistivity values were corrected to formation temperature, shows that in the latter case the slope of the plot of resistivity versus depth is more nearly perpendicular to the abscissa. Thus the sudden decrease in resistivity at about 9,800 feet is easier to see when the resistivity has been corrected to formation temperature.

WELL EXAMPLES

To demonstrate the effectiveness of the method of this invention resistivity 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 and 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, passing through a 10 mesh screen and retained on a 24 mesh screen, Tyler Standard Screen Scale Sieves, were placed in a blender along with about four parts by weight of distilled water per part by weight cuttings and blended for two minutes to form a slurry.

The temperature of the slurry was determined. The resistivity of the slurry was measured using a Portable Conductivity Bridge RC-7P manufactured by Industrial Instruments, Inc. The results were corrected to a standard temperature of 80°F using the following expression:

$$R_{80} = R_s (T + 6.77/8677) 1/C$$

where

R_{80} = resistivity at 80°F

R_s = measured resistivity, in ohms

T = measured temperature, in degrees F

C = cell constant of the electrode of the conductivity bridge.

The cell constant for the 1 normal potassium chloride solution electrode used was 2.36. The Figure is a plot of resistivity versus depth over the depth interval of from just below 8,000 feet to just above 15,000 feet. FIG. 1 shows that over the interval of from 8,000 feet to about 13,000 feet the resistivity varied over a relatively narrow range of from about 1.5 ohms to about 2.4 ohms. At around 13,300 feet there was a sudden sharp drop in resistivity to about 0.65 ohms. At lower depths the resistivity continued to be generally lower than at depths above 13,300 feet. This sharp drop in resistivity indicated that the drill bit was approaching a high pressure zone. Controlled drilling procedures were then instigated, i.e., a constant rotary speed and weight on the bit was maintained while penetration rate was monitored. When the penetration rate began to increase, indicating that the high pressure zone was being drilled into, the weight of the drilling mud was then increased in accordance with well known procedures to offset this high pressure. The well was drilled into the high pressure zone and to the total depth desired without difficulty.

To further illustrate the process of this invention resistivity measurements were made as described above during the drilling of a South Texas Well. FIG. 2 shows a plot of these resistivity values, corrected to 80°F, over the depth interval of from 5,000 feet to just below 11,000 feet. A sharp decrease in the resistivity at about 9,800 feet indicated that the drill bit was approaching a high pressure zone. Thus controlled drilling procedures were started and the mud weight increased when the penetration rate increased as described above. The well was drilled into the high pressure zone and to the total depth desired without difficulty.

To illustrate the effect of correcting the resistivity values to the temperature at which the samples existed in the formation, the resistivity values for the South Texas well were corrected as described above and re-plotted versus depth. This plot is shown in FIG. 3. It is seen that the shape of the curve remains the same but the slope is changed. By making this correction for formation temperature, the sharp decrease in resistivity indicating the approach of a high pressure zone is somewhat easier to visually detect.

The foregoing discussion and description have been made in connection with preferred specific embodiments of the process for detecting geopressure 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 resistivity measurements on a slurry made from shale cuttings, such measurements or conductivity measurements may be made on slurries made using formation samples taken with a sidewall cutting apparatus. Further resistivity or conductivity 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 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. determining an electrical characteristic of a sample of the subterranean strata being drilled,

c. when the rate of change of such electrical characteristic with depth begins to change greatly, instituting controlled drilling procedures, and thereafter

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 electrical characteristic is resistivity.

3. The method of claim 1 wherein the electrical characteristic is conductivity.

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. The method of claim 2 wherein the resistivity is corrected for the temperature of the formation whose resistivity is being measured.

6. 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. determining the resistivity of a sample of the subterranean strata being drilled,

c. when the resistivity begins to decrease substantially 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.

7. The method of claim 6 wherein the resistivity is corrected for the temperature of the formation whose resistivity is being measured.

8. 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. determining the conductivity of a sample of the subterranean strata being drilled,

c. when the conductivity begins to increase substantially 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.

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