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METHOD FOR DETERMINING FORMATION PRESSURES

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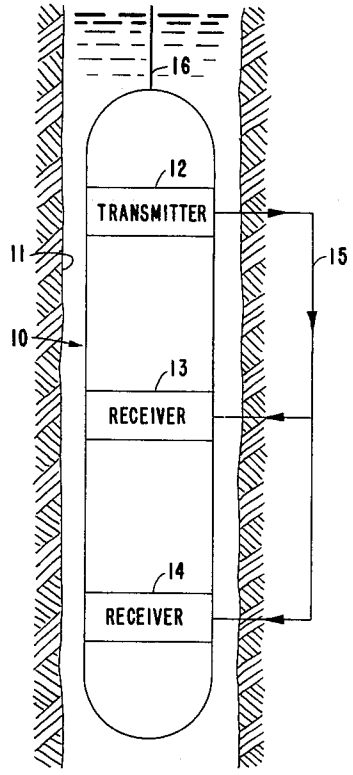



FIG. 1

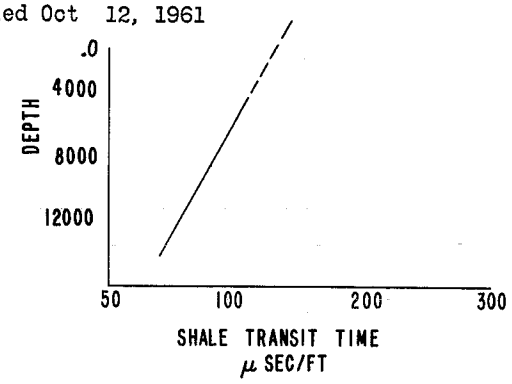



FIG. 2

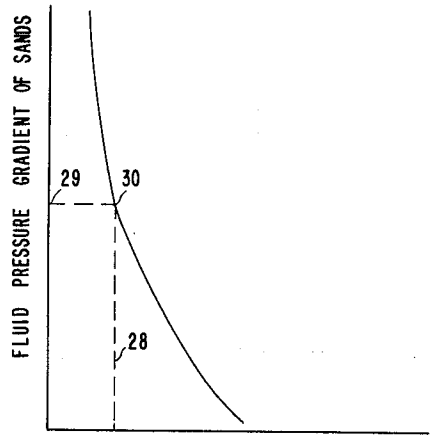



FIG. 4

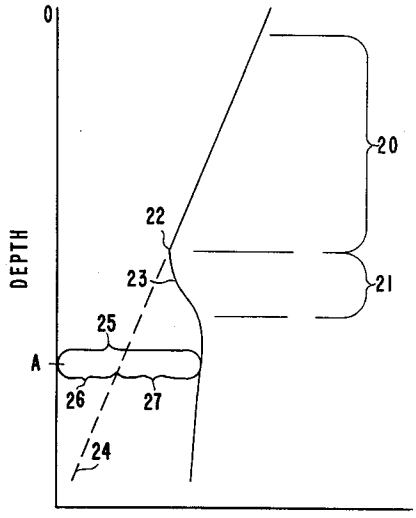



FIG. 3

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# METHOD FOR DETERMINING FORMATION PRESSURES

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3 Claims. (Cl. 181—.5)

This invention pertains to a method for determining reservoir fluid pressures and more particularly to a method utilizing acoustical logging techniques for determining when a well enters a section in which the fluid pressures exceed the hydrostatic head.

In many well drilling operations it is desirable to determine the fluid pressure of the various formations penetrated by the borehole. For example, when wells are drilled in formations having fluid pressures that exceed the hydrostatic head for the depth of the formation it is necessary to take certain precautions to prevent undue damage from the abnormally high pressure. These formations are normally known as abnormally high pressure formations. The cost of drilling a 15,000 foot well with 5,000 feet of abnormal pressure section is frequently two to four times the cost of drilling a 15,000 foot well in a normal pressure section. This cost could be considerably reduced if it were possible to detect at what depth the borehole enters the abnormal pressured section. Knowing when the abnormal pressure section is penetrated would permit the use of normal drilling techniques until this penetration. The ability to use normal techniques for part of the well would considerably reduce the overall cost of drilling the well. The added cost of drilling an abnormally pressured formation results from the increased cost of the drilling mud due to the requirement that it be heavier in order to contain the high pressures. The increased weight of the drilling mud results in a decrease in the drilling rate and more frequent fishing jobs to recover stuck drill pipe. In addition the frequency of lost circulation is increased. In addition to the increased costs of using heavier muds, costs are further increased by the necessity of employing heavier casing and additional strings of casing than are used in normally pressured formations.

In addition to the above it is desirable in many fields of petroleum exploration to know the fluid pressure of formations penetrated by a borehole. The present practice requires that a portion of the formation be isolated and then the formation pressure determined by use of various instruments. This procedure of course requires considerable equipment and time that results in a large expense. Thus, in many cases where formation pressures would be useful they are not obtained.

Accordingly, it is the principal object of this invention to provide a novel method for detecting the fluid pressures of formations penetrated by a borehole.

Another object of this invention is to provide a unique method using acoustical logging techniques to determine fluid pressures of formations penetrated by a borehole.

A further object of this invention is to provide a novel method utilizing acoustical logging techniques to detect where a well penetrates an abnormally high pressured section prior to the penetration of a permeable reservoir formation.

The above objects and advantages of this invention are achieved by determining the travel time of acoustical impulses through the shale formations traversed by the borehole. The measurements of the travel time are made at frequent intervals during the drilling of the well and a plot of the travel times of the shale sections with depth is maintained. As the borehole enters the abnormally pressured formation the rate at which the transit times of the acoustic impulses decrease with each increment of depth becomes less than the rate exhibited in the normally pressured formations. At this point the transit times increase in respect to those which would be predicted from the rate of decrease in the normally pressured formations. The point at which the transit or travel time of the acoustical impulse increases indicates the penetration of the abnormally pressured section. Thus, it is possible to drill the portion of the well above the abnormally pressured section using normal drilling techniques and only the portion of the well which actually penetrates the abnormally pressured section will require the high cost special techniques. This will result in an over-all reduction of the drilling cost of the complete well.



The fluid pressures of the formations penetrated by the borehole can be determined from the acoustical log data. It has been discovered that for many formations the fluid pressure of the formation is related to the transit time of acoustical impulses through the formations. This discovery was made by making a direct comparison of measured formations pressure parameter to an acoustic parameter. Thus, it is possible to predict the fluid pressure of formations penetrated by the borehole.

The above objects and advantages of this invention will be more easily understood from the following detailed description of a preferred embodiment of the method when taken in conjunction with the attached drawing, in which:

FIGURE 1 represents a simplified block diagram of an acoustical well logging tool;

FIGURE 2 is a plot of the transit time of acoustical impulses with depth for a normally pressured section;

FIGURE 3 is a schematic plot of the transit time of acoustical impulses with depth for a complete well showing the change in transit time as the borehole penetrates the abnormally pressured section; and,

FIGURE 4 is a plot of the fluid pressure gradient with the difference between the transit time in the abnormal pressured section and the normal pressured section.

Abnormally pressured sections occur in many different geographical locations where it is desired to drill oil wells. One particular geographical location is the Texas-Louisiana Gulf Coast Region of the United States that have tertiary shale formations of great thickness. These shale formations are usually deep water marine shales that contain few sand formations and are subjected essentially to a uniaxial compaction as a result of the compressive stress of the overburden.

In order for a shale formation to compact the fluids contained in the formation must be removed. The fluids can only be removed by flowing into said sand formations or other permeable avenues of escape. Since the thick shale formations that occur in the Gulf Coast Area have very few sand formations to act as avenues of escape the fluids are removed at a much slower rate than from thinner shale formations sandwiched between sand formations. This inability of the fluid to escape from the shale formations results in the creation of abnormal pressures within the formation.

The creation of abnormal pressures within a shale formation can be more easily understood by considering the following conception of a shale model. The shale model is formed from perforated metal plates which are separated by springs and water with the complete structure being enclosed within a cylindrical tube. The springs simulate the communication between the clay particles while the plates themselves simulate the clay particles. Upon the application of pressure to the uppermost plate the height of the springs between the plates remains unchanged as long as no water escapes from the system. Thus, in the initial stage the applied pressure is supported entirely by the equal and opposite pressure of the water. As the water escapes from the system through the perfora-

tions in the plate the uppermost plate will move downward slightly and the springs will carry part of the applied load. As more water escapes the springs will carry additional load until finally the complete axial load will be borne by the springs and the system will reach a state of equilibrium.

The clay particles forming a shale formation undergo a similar movement to that described above for the model when subjected to a uniaxial compaction due to the overburden. All formations are subject to an axial compaction but more permeable formations reach equilibrium much faster than shale formations. The inability of shale formations to reach equilibrium results in the occurrence of abnormal high pressured shale and abnormally high pressures in the fluids contained in permeable rocks which are enclosed within such shales.

Referring now to FIGURE 1, there is shown a simplified block diagram of an acoustical well logging tool. The tool **10** is lowered into a borehole **11** by means of a logging cable **16**. The tool includes a transmitter **12** and two spaced receivers **13** and **14**. The tool electronically records a function of the minimum time path for impulses generated at the transmitter **12** and propagated to the receivers **13** and **14**. This minimum time path is roughly illustrated by the line **15** in FIGURE 1.

The transmitter and the two receivers transmit suitable electrical signals over the cable **16** to a surface recording system that indicates the generation of the acoustical impulse and the receiving of this impulse at the two receivers. From this information one can easily determine the travel time of the acoustical impulse over the distance separating the two receivers. This is an accurate indication of the travel time of the impulses through the formation since it removes the time required for the impulses to travel from the transmitter through the borehole fluid to the formation and from the formation to the receivers.

Referring now to FIGURE 2 there is shown a plot of the shale travel time of the acoustic impulses in microseconds per foot with relation to the depth of the formation. In addition the shale travel time is plotted in a logarithmic scale that results in a linear relationship between the shale travel time and the depth. The information plotted in FIGURE 2 is for a representative section occurring in the Gulf Coast Area, for example, a Miocene section. Sections from older geological ages, for example, the Oligocene or the Eocene have a similar linear relationship except that they have a greater slope indicating that the shales are more compact and that the travel time is shorter indicating a higher velocity. This result would, of course, be expected for shales of older geological ages that have had a longer time to reach equilibrium and thus become more compacted.

Referring now to FIGURE 3 there is shown a schematic plot of the shale transit time versus depth for a well drilled in an abnormal pressured formation. The section of the curve **20** represents the portion of the well drilled in a normally pressured section and has a similar characteristic to the information plotted in FIGURE 2. At the point **22** the transit time reverses and starts to increase. Point **22** then is the top of the abnormal pressure section. The transit time increases over a period **21** and finally assumes a new slope below the point **23**. From the point **23** on, the transit time decreases in much the same manner as it would in the normally pressured section of the well.

The schematic drawings in FIGURES 2 and 3 clearly illustrates that for normally pressured shale formations the acoustical velocity increases at a constant rate and thus the transit time decreases at a constant rate. When an abnormally pressured shale formation is penetrated as shown in FIGURE 3, the transit time still decreases with depth but at a rate different than for the normally pressured section.



FIGURE 4 represents a plot for a Miocene Age formation used in FIGURE 3 of the fluid pressure gradient of sands (pressure/depth) and the difference between the transit time for the abnormal pressured adjacent shale section and the shale transit time if the section was normally pressured. The normal shale transit times were obtained by projecting the shale transit time for the normally pressured section as shown by the dotted line **24** in FIGURE 3. The data for the curve in FIGURE 4 was obtained by taking the difference in transit times between the abnormal section and the normal section and plotting it versus the fluid pressure gradient for the depth at which the transit times were measured. For example, in FIGURE 3 at the depth A the actual transit time is the quantity 25 while if the shale section was normally pressured the transit time would be the quantity 26. The difference between the quantities 25 and 26 or the quantity 27 is then plotted in FIGURE 4. The fluid pressure gradients in FIGURE 4 were obtained by measuring the formation pressure at the depth A and then computing the fluid pressure gradient.

From the information plotted in FIGURES 2 and 3, it is easily appreciated that the point **22** which is indicated by an increase in the transit time denotes the point at which the borehole entered the abnormally pressured section. Thus, it would be possible to drill the well using normal techniques until the depth indicated by the point **22** was reached. At this point it would be necessary, of course, to adapt the techniques used for drilling the abnormally pressured wells.

The data plotted in FIGURE 4 can be used to determine the weight of the drilling mud required to drill at various depths in the abnormally pressured sections. For any given depth the difference in transit times will have a unique value, for example, the value indicated by the dotted line **28** of FIGURE 4. The value 28 of the transit time will intersect the curve of FIGURE 4 at a point **30** which will give a fluid pressure gradient value 29. The fluid pressure gradient is directly related to the required mud weight, thus the value 29 may easily be used to give the required mud weight.

The data used in FIGURES 3 and 4 is for a single geological age, for example, the Miocene. Other geological ages, such as the Oligocene will have similar characteristics but slightly different values. These values can easily be determined by utilizing the method of this invention. Of course the data for a particular geological age remains constant from well to well. Accordingly this invention will indicate when the well has penetrated the abnormally pressured section and the mud weight required to drill the section. Similarly the fluid pressure gradient can be determined utilizing the method of this invention.

While but a single embodiment of this invention has been described in detail it should not be limited to these details but only its broad spirit and scope.

I claim as my invention:

**1.** A method for detecting the fluid pressure gradient of a permeable subsurface earth formation, said method comprising: generating acoustical impulses at a point in said borehole adjacent to a shale formation; detecting the arrival of said impulses at points spaced from the point of generation and disposed adjacent to said shale formation; recording the travel time of said impulses with relation to the depth of said point of generation in the borehole; continuing to generate said impulses and record said travel times as said borehole is drilled and utilizing the difference between said recorded travel times in abnormally pressured shale formations penetrated by the borehole and a projection of the travel times in normally pressured shale formations penetrated by the borehole to determine the fluid pressure gradient of an adjacent permeable sursurface earth formation.

**2.** A method for detecting the fluid pressure gradient of a permeable subsurface earth formation, said method

comprising: generating acoustical impulses at a point in said borehole adjacent to a shale formation; detecting the arrival of said impulses at points spaced from the point of generation and disposed adjacent to said shale formation; recording a property of said impulses with relation to the depth of said point of generation in the borehole; continuing to generate said impulses and record said property as said borehole is drilled and utilizing the difference between said recorded property in abnormally pressured shale formations penetrated by the borehole and a projection of the travel times in normally pressured shale formations penetrated by the borehole to determine the fluid pressure gradient of an adjacent permable subsurface earth formation.

3. A method for determining the pressure to be expected in a reservoir, said method comprising: measuring the rate of change with depth of the acoustical velocity in a vertical sequence of normally compacted shales; measuring the acoustical velocity in an under-compacted



shale below said sequence and utilizing the difference between the measured value and the value that would be exhibited by a normally compacted shale at the depth of the measurement to predict the pressure in a reservoir in the undercompacted shale at the said depth.

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