A method for evaluating permeability of Earth formations includes determining a transverse nuclear magnetic relaxation spectrum by performing a nuclear magnetic resonance experiment directly on drill cuttings of the Earth formation removed from a wellbore, and estimating permeability from the transverse nuclear magnetic relaxation spectrum.
FIG. 2

Permanent magnet 50

Drill cuttings 54

NMR Antenna 56

System Control Computer 52

FIG. 3

Pulsed RF current

EMF
METHOD FOR ANALYZING DRILL CUTTINGS USING NUCLEAR MAGNETIC RESONANCE TECHNIQUES

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] Not applicable.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] Not applicable.

BACKGROUND OF INVENTION

[0003] 1. Field of the Invention

[0004] The invention relates generally to the field of evaluation of petrophysical properties of Earth formations. More specifically, the invention relates to methods for evaluating petrophysical properties of Earth formations using samples of drill cuttings and using nuclear magnetic resonance (NMR) measurement and analysis methods.

[0005] 2. Background Art

[0006] Faster drilling and higher drilling cost (especially offshore) dictate reducing cost and decreasing the time required for well evaluation. Simultaneously, it is necessary to ensure the reliability of the results of such evaluation. This is especially important for Earth formation reservoirs that include complicated geology and that may involve long exploitation time, because the in-situ oil viscosity can be different in different parts of a reservoir.

[0007] Formation evaluation techniques include the following, each of which is applicable on a different scale. Variable well test techniques are used for direct reservoir rock hydro-conductivity evaluation. Indirect, continuous well logging measurements such as made by wireline or measurement while drilling are used to evaluate on a so-called "macro scale". Direct and indirect laboratory measurements are used on full-scale cores, core plugs and thin sections. The above methods known in the art have a number of limitations. At any given time such measurements sample only one part of the well, and characterization of well cross-sections occurs only after finalizing of the drilling process.

[0008] Formation evaluation "while-drilling" is an increasingly used technique. However, there are various drawbacks. See, for example, Santarelli, F. J., Marsala, A. F., Marco Brignoli, Elio Rossi, and Nicola Bona, 1998, Formation Evaluation From Logging on Cuttings, SPEERE, 238. See also, Geological and Mud Logging in Drilling Control, Catalog of Typical Cases, 1982, Graham and Trotman Limited, Sterling House, Chambre syndicale de la recherche et de la production du petrole et du gaz naturel, Paris-London, and, Petroleum Engineering Handbook, 1992, SPE, Editor-in-Chief Howard B. Bradley. Generally, the lag time before data is available may be long if the rate of penetration of the drill bit through the Earth is slow, and for MWD tools which are so-called “memory-only”, where no data are sent to the surface during active drilling, the lag time can be even longer. Formation evaluation while drilling technologies are relatively expensive and their application requires a high degree of well stability. Interpretation of the results frequently includes operational noise from the drilling process.


[0010] More recently, a number of techniques for quantitative formation characterization have been developed which use drill cuttings analyzed at the well site. See, for example, the Santarelli et al. and Worthington et al. reference cited above. Limitations of the well site techniques known in the art include the following. First, it is difficult to use only one type of measurement to determine the generally required petrophysical parameters, these parameters including fractional volume of pore space in a reservoir formation (porosity), and permeability, that is, the quantitative determination of filtration capacity properties (ICP) require a set of different tools (Santarelli, 1998; Marsala et al., 1977; Nes et al., 1998). It has also proven to take too long to provide quantitative on-line information during drilling on well site.

[0011] Advanced analysis of drill cuttings (mud logging) can be used for the following purposes: rock numenal composition (lithology) determination; estimating formation and mineralogical density of rocks; estimating acoustic parameters of rocks; determining volume percentage of quartz, clay, calcite, dolomite, sulfites etc; grain size analysis of sedimentary rocks; estimating the content of residual oil in the pore spaces of porous formations; and determining the open porosity and absolute permeability on fractions with appropriate sizes of drill cuttings (usually more than about 3 millimeters). See, for example, EXLOG, 1985, Mud Logging Principles & Interpretations, International Human Resources Development Corporation, Boston. However, advanced mud logging at the well site is labor intensive, and thus expensive, and can be applied generally to drill cuttings having particle sizes of more than 3 mm. An automated petrophysical parameter determination would be desirable.
Nuclear magnetic resonance (NMR) methods using so-called “high electromagnetic fields” were used primarily in the former Soviet Union for analysis of drill cuttings. See, Akselrod, S. M., and Neretin, V. D., 1990, *Using Nuclear Magnetic Resonance in Oil and Gas Geology and Geophysics*, Nedra, Moscow (in Russian). High field NMR was so used for porosity determination (POR), evaluation of the irreducible water saturation ($S_{irr}$), free fluid index (FFI) and for estimation of other petrophysical parameters. All NMR measurements were carried out on the coarse size fractions of the drill cuttings. Data processing and interpretation was methodologically identical to NMR data interpretation used on whole core samples. The difficulties of measurements using high field NMR spectrometers, namely the high radio frequency, and difficulty of handling the large size of high field instruments discouraged wider use of this technology at the well site.

More recently, attempts have been made to use so-called “low field” NMR for cuttings investigation. See, for example, the Santarelli et al. publication cited above. However, the processes used on coarse cuttings have not proven effective for determining petrophysical parameters on fine and middle size cuttings.

Other relevant prior art includes the following publications. U.S. Pat. No. 4,699,002 discloses cuttings from oil or gas wells being analyzed to determine the water and light hydrocarbon content in the cuttings. The cuttings may be sieved to remove any powders on their surface, and separated into medium and large size fragments. A medium sized fragment is ground, mixed with potassium bromide (KBr) and tested with a Fourier transform infrared spectrometer to determine its mineral content. The large size cuttings are heated in an oven to burn off their volatiles, and are reweighed to determine their heavy hydrocarbon content. The large size cuttings are tested with a helium pycnometer to determine the grain density. A second pycnometer, which uses a clay suspension as the working fluid, is used to determine the bulk density and porosity of the sample and a permeameter which will be used to determine the permeability of the cuttings. A conventional porosimeter may be used to determine the pore size spectrum of the cuttings.

U.S. Pat. No. 5,161,409 discloses a method of quantitative analysis of solids from drilling mud. The disclosed method includes sampling the removed solids, and analyzing the samples to determine the density of the solids and their weight fraction. A known weight of the sample is dried to a constant weight so as to obtain the solids in the form of dry solids, and analysis of the dry solids is performed by an infrared spectroscopy technique. The concentration of the substances in the removed solids is then determined. The method can be applied to the control of the drilling operation by monitoring the quantity of products added to the drilling fluid, such as barite and polymers, or a product coming from the borehole wall or the underground formation being drilled. The disclosed method also applies to the control of working condition of the mud solids equipment.

U.S. Pat. No. 5,686,724 discloses methods for evaluating wet cuttings to determine the hydrocarbon content of reservoir formation. The wet cuttings to be measured are mixed with a polar hydrocarbon solvent, which has both hydrophilic and hydrophilic properties. The solution of the solvent and cutting is filtered and then its emission (fluorescence) spectrum is measured by irradiating it with ultraviolet radiation excitation at wavelengths at which most petroleum compounds fluoresce. The hydrocarbon content of the wet cuttings is then determined by comparing its fluorescence emission to the emission fluorescence of known samples.

Canadian Patent No. 2,256,255 discloses a method for establishing semi-quantitative values indicative of porosity and permeability of a formation through analyzing rock cuttings during drilling. A drilling mud sample is analyzed and the proportions of each solid grain constituent are classified into respective grain size divisions. Each proportion is multiplied against a corresponding weighting factor for establishing values representative of the relative contribution to the formation’s porosity and when summed they establishing numeric values corresponding to an environmental index related to the porosity of the formation. Through the assignment of values for ranges of other conventional qualitative characteristics, similar and useful semi-quantitative value of relative permeability can be determined which is proportional to the environmental index, grain angularity, extent of sorting, porosity and is inversely proportional to the extent of cementation.

U.S. Pat. No. 6,453,727 discloses a system of evaluating physical parameters such as absolute permeability of to remove of reservoir formation from cuttings. Rock fragments (drill cuttings) are immersed in a viscous fluid contained in a vessel, then inject into vessel a fluid under pressure that increases with time, up to a determined pressure threshold, so as to compress the gas trapped in the pores of rock. The injection stage is followed by a relaxation stage with injection stop. The pressure variation measured by detectors during these two successive stages is recorded by a computer. The evolution of the pressure during the injection process is modeled from initial values selected for physical parameters of cuttings. The computer adjusts them iteratively so as to best obtain the modeled pressure curve to coincide with the pressure curve actually measured.

Nuclear magnetic resonance (NMR) imaging methods for determining the spatial petrophysical properties of materials are disclosed in U.S. Pat. No. 4,728,892. The disclosed methods use the generation of separate $T_1$, $T_2$, and $T_2^*$ images from which various petrophysical characteristics may be obtained, such as free fluid index, porosity, pore sizes and distribution, capillary pressure, permeability, formation factor and clay content.

U.S. Pat. No. 5,486,762 discloses a method for NMR well logging when a pulsed nuclear magnetic resonance (NMR) well logging tool is traversing a wellbore. A disclosed NMR well logging method includes magnetizing the hydrogen nuclei in a formation traversed by the tool with a static magnetic field, waiting for a first period of time $T_1$, energizing the formation with oscillating RF magnetic fields, collecting a first plurality of spin echo signals, waiting a second period of time $T_2$ which is different from the first period of time $T_1$, energizing the formation with oscillating RF pulses, collecting a second plurality of spin echo signals, waiting a third period of time $T_3$ which is different from both the second period of time $T_2$ and the first period of time $T_1$, energizing the formation with oscillating RF pulses,
collecting a third plurality of spin echo signals, etc. The first, second and third, etc. plurality of spin echo signals corresponding to the different wait times are input to a signal processing apparatus disposed in the tool. Window sums of spin-echo signals are computed and transmitted uphole to a surface oriented signal processing apparatus. In response to the window sums, the surface signal processing apparatus determines an apparent formation $T_2$-distribution for each wait time in the multi-wait time pulse sequence. The apparent $T_2$-distributions are used to construct a cost function. When the cost function is minimized, the surface oriented signal processing apparatus determines estimates of the true $T_1/T_2$ ratios and intrinsic $T_2$-distributions of the formations being logged. The surface signal processing apparatus uses the new $T_2$-distribution to generate new, more accurate, output record medium.

[0021] U.S. Patent No. 5,696,448 discloses a pore-level model for diffusion and NMR relaxation of oil-water mixtures in water wet pores. In addition to lending physical insight into the relaxation time behavior of mixed pore fluids, the disclosed model can be used to generate a practical tool for interpreting diffusion log data, i.e., a $T_2$ vs. D cross plot. Locating points on the cross plot simultaneously yields the near wellbore water saturation and the rock pore size. For light oils, $T_2$ is shown to be mainly a pore size indicator whereas D is controlled mainly by $S_w$. The pore size “resolution” decreases as oil viscosity and/or $S_w$ decreases. A preliminary verification of the disclosed model was made with limited core data and the results of applying the model to interpreting NMR log data are encouraging. The capability to separate the effects of pore size from fluid saturation on NMR response of pore fluids indicates an important potential advantage of the $T_2$ and D measurement combination over standard $T_2$ logging for characterizing formation pore size and related reservoir flow properties.

[0022] Canadian Patent No. 2,288,447 discloses a method for determining formation properties using NMR logging measurements. During NMR logging data acquisition, RF magnetic fields are transmitted, a plurality of times with a respective plurality of different transmitting and/or receiving conditions, to obtain a plurality of measurements. Then a formation model is generated that includes a plurality of model components for a brine phase and a plurality of model components for a native oil phase. The model components are modified to optimize the model with respect to the measurement signals, and model components of the optimized model are output. Depending on the circumstances, generating the formation model can include generating a model that further includes an oil base mud filtrate component and/or can include a gas component. In one embodiment, the step of generating a formation model includes generating a set of model amplitude components that define the transverse relaxation time distribution of the brine phase, native oil, and a further set of model components that define the constituent viscosities of the native oil.

[0023] Canadian Patent No. 2,397,385 discloses a multi-frequency method and NMR logging apparatus for measuring volumes of hydrocarbon gas and oil. The apparatus and method uses a triple-wait-time (TWS1, TWS2, TWL) NMR sequence to determine gas and light-oil filled porosity over a broad range of reservoir conditions. A set of conditions is derived for the selection of optimum acquisition parameters. The conditions are developed to aid in the selection of wait time combinations.

[0024] U.S. Patent Application Publication No. 2002/0167314 discloses a NMR logging system and method for detecting the presence and estimating the quantity of gaseous and liquid hydrocarbons in the near wellbore zone. The system uses a gradient-based, multi-frequency NMR logging tool to extract signal components characteristic for each type of hydrocarbons. Methods are disclosed in which measurements at different frequencies are interleaved to obtain, in a single logging pass, multiple data streams corresponding to different recovery times and/or diffusivity for the same spot in the formation. The resultant data streams are processed to determine mineralogy-independent water and hydrocarbon saturations and porosity estimates. Gas and oil saturations are used to obtain accurate estimates of water content, permeability and other parameters of interest. In another aspect, a diffusion-enhanced data acquisition sequence is disclosed for use with low field gradient tools.

[0025] U.S. Patent No. 6,661,226 discloses NMR logging apparatus and a multi-frequency method using triple-wait-times for determining gas- and light-oil-filled porosity over a broad range of reservoir conditions. The method improves the signal-to-noise ratio and the determination of $T_2$ values for hydrocarbons, especially when the reservoir contains different fluid types. A set of conditions is derived for the selection of optimum acquisition parameters for logging applications. The data acquisition and processing method enables accurate determination of pore volumes occupied by each hydrocarbon phase as well as the pore volume occupied by water, as well as accurate $T_2$. A set of conditions is developed to aid in the selection of wait-time combinations appropriate for logging conditions.

[0026] There exists a need for method and apparatus to quantitatively evaluate drill cuttings at the well site, substantially in real time for selected petrophysical properties.

SUMMARY OF INVENTION

[0027] One aspect of the invention is a method for evaluating permeability of Earth formations. A method according to this aspect of the invention includes determining a transverse nuclear magnetic relaxation spectrum by performing a nuclear magnetic resonance experiment directly on drill cuttings of the Earth formation removed from a wellbore, and estimating the permeability from the transverse nuclear magnetic relaxation spectrum.

[0028] Other aspects and advantages of the invention will be apparent from the following description and the appended claims.

BRIEF DESCRIPTION OF DRAWINGS

[0029] FIG. 1 shows a typical well drilling system with which the invention may be used.

[0030] FIG. 2 shows a portable laboratory instrument measuring a property of drill cuttings of Earth formations.

[0031] FIG. 3 shows magnetic field arrangements of an example NMR experiment being performed on drill cuttings

DETAILED DESCRIPTION

[0032] FIG. 1 shows a typical wellbore drilling system which may be used with various embodiments of the inven-
tion. In FIG. 1, a drilling rig 10 includes a drawworks 11 or similar lifting device known in the art to raise, suspend and lower a drill string. The drill string includes a number of threadedly coupled sections of drill pipe, shown generally at 32. A lowermost part of the drill string is known as a bottom hole assembly ("BHA") 42, which includes, in the embodiment of FIG. 1, a bit 40 to cut through earth formations 13 below the earth's surface. The BHA 42 may include various devices such as heavy weight drill pipe 34, and drill collars 36. The BHA 42 may also include one or more stabilizers 38 that include blades thereon adapted to keep the BHA 42 roughly in the center of the wellbore 22 during drilling. In various embodiments, one or more of the drill collars 36 may include a measurement while drilling ("MWD") sensor and telemetry unit (collectively "MWD system"), shown generally at 37.

[0033] The drawworks 11 is operated during active drilling so as to apply a selected axial force to the drill bit 40. Such axial force, as is known in the art, results from the weight of the drill string, a large portion of which is suspended by the drawworks 11. The un suspended portion of the weight of the drill string is transferred to the bit 40 as axial force. The bit 40 may be rotated by turning the pipe 32 using a rotary table/kelly bushing (not shown in FIG. 1), or preferably may be rotated by a top drive 14 (or power swivel) of any type well known in the art. While the pipe 32 (and consequently the BHA 42 and bit 40) as well is turned, a pump 20 lifts drilling fluid ("mud") 18 from a pit or tank 24 and moves it through a stand pipe/hose assembly 16 to the top drive 14 so that the mud 18 is forced through the interior of the pipe segments 32 and then the BHA 42. Ultimately, the mud 18 is discharged through nozzles or water courses (not shown) in the bit 40, where it lifts drill cuttings (not shown separately in FIG. 1) to the earth's surface through an annular space between the wall of the wellbore 22 and the exterior of the pipe 32 and the BHA 42. The mud 18 then flows up through a surface casing 23 to a wellhead and/or return line 26. After removing drill cuttings using screening devices (not shown in FIG. 1), the mud 18 is returned to the tank 24.

[0034] The standpipe 16 can include a pressure transducer 28 which generates an electrical or other type of signal corresponding to the mud pressure in the standpipe 16. The pressure transducer 28 is operatively connected to systems (not shown separately in FIG. 1) inside a recording unit 12 for decoding, recording and interpreting signals communicated from the MWD system 37. As is known in the art, the MWD system 37 includes a device, which will be explained below with reference to FIG. 1A, for modulating the pressure of the mud 18 to communicate data to the earth's surface. In some embodiments the recording unit 12 includes a remote communication device 44 such as a satellite transceiver or radio transceiver, for communicating data received from the MWD system 37 (and other sensors at the earth's surface) to a remote location. Such remote communication devices are well known in the art. The data detection and recording elements shown in FIG. 1, including the pressure transducer 28 and recording unit 12 are only examples of data receiving and recording systems which may be used with the invention, and accordingly, are not intended to limit the scope of the invention. The top drive 14 may also include a sensor, shown generally at 14B, for measuring rotational speed of the drill string, and the torque applied to the drill string. The signals from these sensors 14B may be communicated to the recording unit 12 for processing. A sensor for measuring axial load supported by the top drive 14 is shown at 14A, and is referred to as a "weight on bit" sensor or "hookload" sensor.

[0035] Methods according to the invention use the drill cuttings removed from the drilling mud 18 to analyze the mineral content and fluid content of the various Earth formations that are drilled by the drill bit 40.

[0036] FIG. 2 shows a portable laboratory instrument measuring at least one NMR property of cuttings of Earth formation for laboratory or well site mud logging applications. The instrument typically includes at least one static magnetic field source, at least one radio frequency (RF) magnetic field detector, and suitable operating and communication circuits, shown schematically in FIG. 2, to control operation of the source (where a controllable-operation source is used such as a wire coil coupled to a direct current electric power source), to control operation of the at least one RF magnetic field detector, and to condition signals from the RF magnetic field detector for recording and/or transmission to the recording unit (which may be the computer).

[0037] In the present embodiment, the static magnetic field source is a permanent magnet 50. A radio frequency transmitter antenna 56 is coupled to suitable driver circuits (part of the operating circuits in the computer 52). In such embodiment, the detector is a radio frequency receiver antenna coupled to suitable receiver circuits (also part of operating circuits in the computer 52). The control circuits may include, for example, a pulse programmer, a receiver/detector, and other circuits for performing NMR measurements in the cuttings of Earth formations, and where appropriate, to communicate the measurements to the recording unit.

[0038] In the present embodiment, the static magnetic field produced by the magnet is used to polarize the drill cuttings 54 of the Earth formations along a first direction. The radio frequency (RF) antenna 54 is oriented to emit a radio frequency magnetic field transverse to the static magnetic field. The circuits 52 periodically conduct controlled duration pulses of RF power through the antenna. The drill cuttings 54 of Earth formations are thus repeatedly transversely magnetically polarized with the RF magnetic field to induce nuclear magnetic resonance spin echo phenomena in the samples of Earth formations. The antenna 54 can be alternately coupled to the receiver circuit (not shown separately) to detect RF energy emitted by the spin echoes. Amplitudes of the spin echoes are inferred form the RF detection amplitude.

[0039] FIG. 3 represents a simplified scheme used for measuring NMR signal of core plugs or cuttings. The sample is placed in a substantially homogeneous static magnetic field having amplitude $B_0$ of a permanent or electro-magnet. A pulsed RF current in the antenna coil generates RF magnetic field having amplitude $B_1$. Typically the same antenna coil is used in receive mode to detect the NMR signal induced by x-y component $M_{xy}$ of precessing nuclear magnetization $M$. The NMR signal can be calculated based on the Reciprocity Principle that for the simple example presented in FIG. 2 gives the following expression

$$E_{x} = -\gamma M_{xy} B_{1} B'$$

(1)
where $E$ is the amplitude of the measured NMR signal, $\omega$ is the NMR frequency, $M_x$ is the magnitude of the transverse component of nuclear magnetization of the sample in laboratory coordinate system, $B_1$ is the NMR antenna sensitivity function defined as the antenna magnetic field that would be generated by the antenna coil driven with current of 1 Ampere, and $V$ is the sample volume.

Having shown the basic process by which drill cuttings are analyzed, methods according to the invention will now be explained. The amount of quantitative petrophysical data that can be obtained from cuttings depends primarily on the size of cuttings that are available for evaluation. Earlier studies indicated practical lower limits of cuttings size for quantitative determination of NMR porosity ($\text{POR}_{\text{NMR}}$) on Earth formation samples as larger than about 3 mm. See the Tulovich, 1990 and Akselrod et al., 1990 publications referred to in the Background section herein. It has been demonstrated that accurately accurate determination of $\text{POR}_{\text{NMR}}$ from drill cuttings could be obtained for petrophysical characterization of hydrocarbon bearing rocks where such sample size limitations were observed. The previous investigations which led to such conclusions were based on longitudinal NMR relaxation times ($T_1$ values). However, the NMR porosity determined from non-water-wet (hydrophobic) porous media is systematically underestimated with respect to real porosity. Thus, NMR porosity (and thus permeability) estimates of drill cuttings can only be used when the measurements are not affected by anomalous formation fluids and wettability conditions. A practical

In the invention, a model has been devised which enables NMR estimation of permeability from drill cuttings without the need to specially prepare the cuttings. The ability of the model to be used for such estimation results from the model output being relatively insensitive to the type of fluid saturating the pore spaces of the rock, provided that certain criteria for filtration radius in the pore spaces of the rock are met. Generally, permeability of a porous rock (PERM) can be defined with respect to effective fractional volume of pore space ($\text{Oeff}$) by the relationship

$$\text{PERM} = \text{Oeff} \times \text{PSD} \times \text{GSA} \times \text{(2)}$$

where PSD represents the pore size distribution, and GSA represents results of grain size analysis. Effective porosity can be determined from transverse relaxation ($T_2$) spectral analysis of NMR measurements made on the drill cuttings.

The model in the invention is for permeability determination of the rock samples in six clusters. The classification of clastic rocks (six clusters) is described in Kamin, A. A., 1976, Petrophysics of oil and gas reservoirs, p. 295, Moscow, Nedra (in Russian). The solution for the model according to the invention relates permeability and effective porosity according to the expression:

$$\log \text{PERM} = a \times \text{Oeff} + b$$

where $\text{Oeff}$ represents the effective porosity determined based on identified $T_{2\text{ cutoff}}$ values. The $T_{2\text{ cutoff}}$ values were determined from NMR experiments performed on a statistically representative set of whole cores and drill cuttings samples (11347 total samples) collected from different oil and gas saturated clastic deposits around the world. The samples represent different Kamin-clusters of clastic rocks. Determining porosity parameters from NMR measurements is known in the art. See, for example, Appel, M., TUTORIAL: Nuclear Magnetic Resonance and Formation Porosity, Petrophysics, vol. 45, no. 3, Society of Professional Well Log Analysis, Houston, Tex. (2004).

The coefficients $a$ and $b$ were found empirically for each “cluster.” Criteria for $\text{Oeff}$ determinations were developed using generalized NMR parameters ($T_3$ spectra) for each cluster. The NMR data for the core samples used in experimental verification of the model were measured under different saturation conditions. The model includes as empirical parameters: minimum ($M_{\text{min}}$) and maximum ($M_{\text{max}}$) effective porosity for filtrating pores with filtration radius ($R_p$) $R_p = 5 \mu$m and $R_p = 2 \mu$m, respectively. The model verification also included the lithology of each rock sample.

In use at a wellsite, the input information for the model is the NMR spectra ($T_2$ vs. $A$, $T$, and A visual lithology estimation or description. Examples of the latter include coarse grained sandstone and fine grained siltstone. The model produces results that are substantially independent of the fluid saturation conditions (conventional oils with viscosity up to 20 cps. or brine) and cover most of the “clusters” representing clastic rocks. At the wellsite, drill cuttings removed from the wellbore are directly evaluated by performing an NMR experiment on the cuttings. $T_2$ distribution measured from the NMR experiment on the cuttings is used to determine effective and/or total porosity as explained above. The effective porosity thus determined is then applied to the model with the appropriate lithology description to provide an estimate of the permeability of the Earth formation. The depth from which the cuttings were drilled in the Earth can be correlated to the depth of the drill bit (FIG. 1) using “mud logging” techniques well known in the art.

Laboratory verification of NMR permeability estimates for drill cuttings are comparable to estimates of permeability using conventional methods on whole cores. Even for 1-3 mm cuttings sizes (proven for Berea sandstone), the agreement between permeability from NMR drill cuttings analysis and permeability from analysis of whole cores is acceptable. For clastic Earth formations, cuttings size larger than about 1 mm is acceptable for accurate permeability estimates from NMR measurements.

While the invention has been described with respect to a limited number of embodiments, those skilled in the art, having benefit of this disclosure, will appreciate that other embodiments can be devised which do not depart from the scope of the invention as disclosed herein. Accordingly, the scope of the invention should be limited only by the attached claims.

What is claimed is:

1. A method for evaluating permeability of Earth formations, comprising:
   determining a transverse nuclear magnetic relaxation spectrum by performing a nuclear magnetic resonance experiment directly on drill cuttings of the Earth formation removed from a wellbore; and
   estimating the permeability from the transverse nuclear magnetic relaxation spectrum.

2. The method of claim 1 further comprising determining effective porosity from the nuclear magnetic resonance measurements.

* * * *