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(54) MEASUREMENTS OF ROCK PARAMETERS

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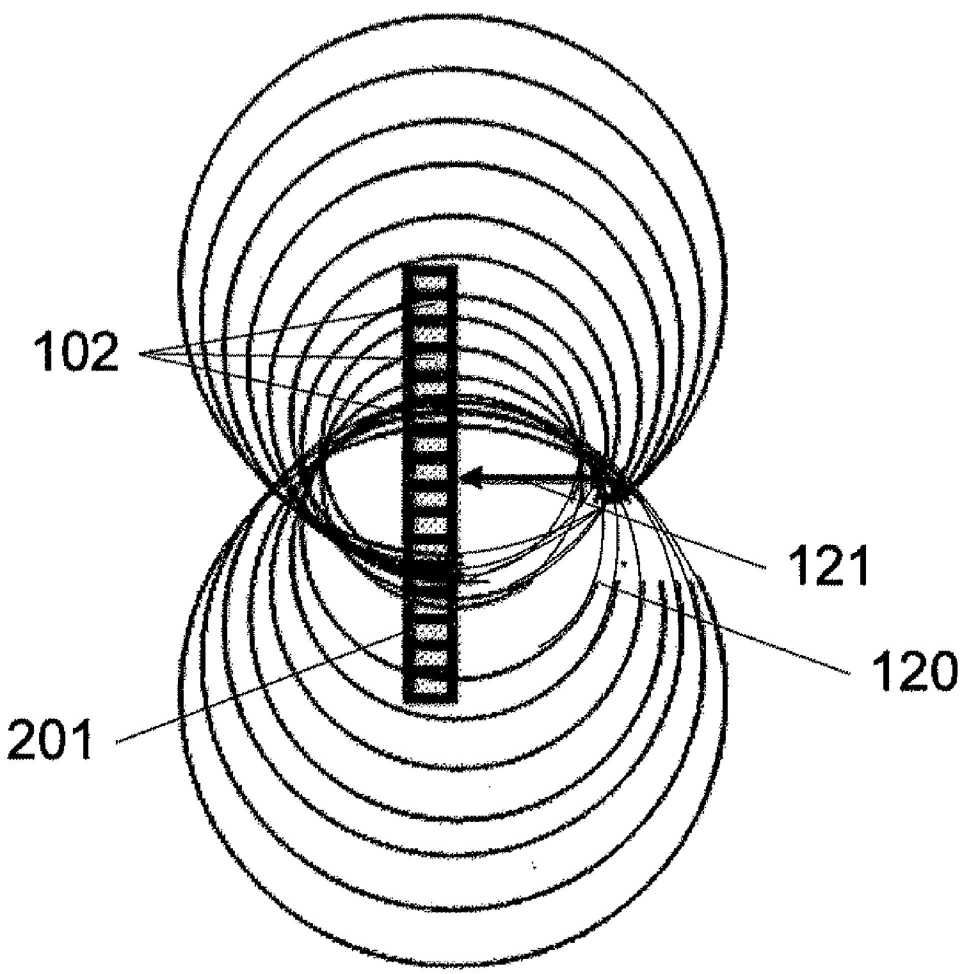
(57) ABSTRACT

Methods and apparatus to measure physical parameters such as density and porosity of the rock matrix in a near wellbore area are provided. A borehole tool having a number of transducer elements in a transducer array is placed at an outermost surface of the borehole tool and is capable of emitting focused high frequency ultrasound beams into the rock matrix in the near wellbore area. The transducer array may be placed on the ribs or stabilizers of the borehole tool, and/or on a sleeve with a lower rotational speed, and may include a fronting material with similar acoustic impedance as the rock matrix. A method for measuring physical parameters of the rock matrix in a near wellbore area is also provided where a focused high frequency ultrasound beam is emitted into the rock matrix in the near wellbore area from one or more transducer arrays on a borehole tool.



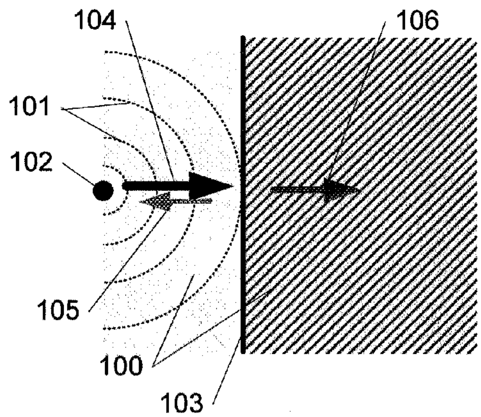


Fig. 1

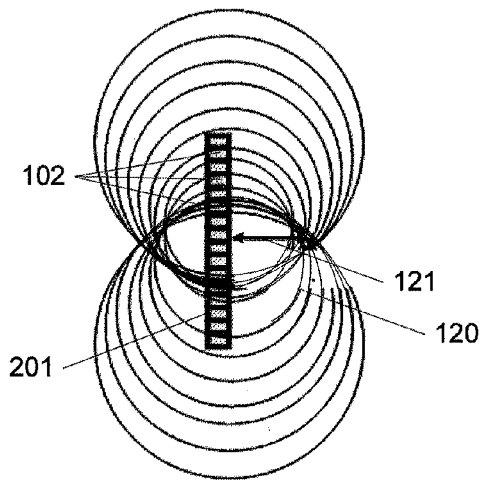


Fig. 2

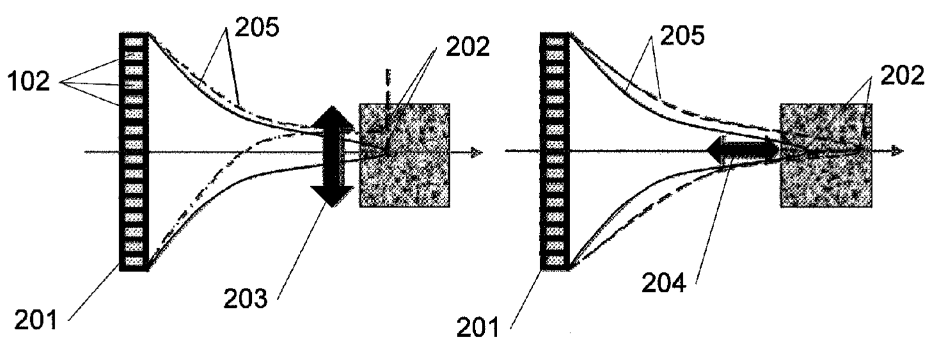


Fig. 3

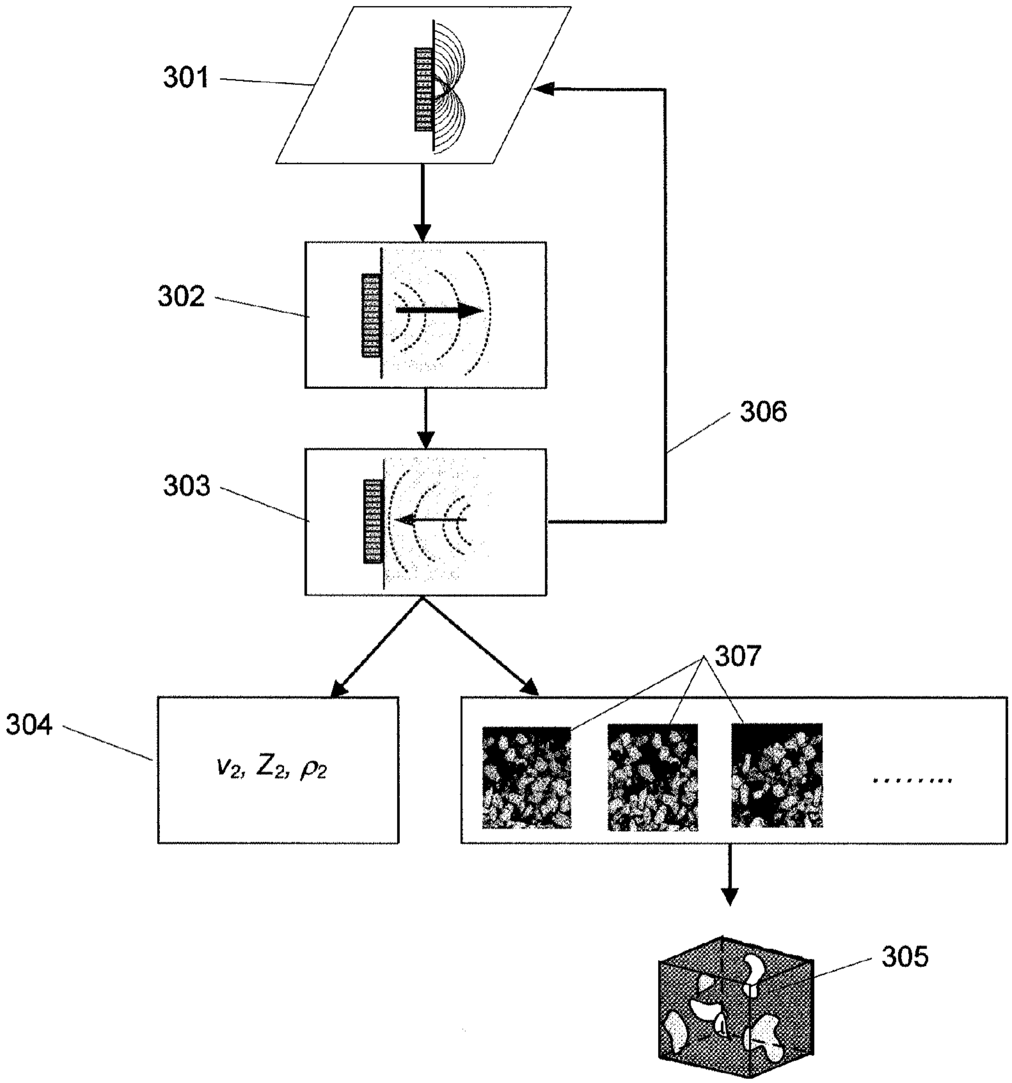


Fig. 4

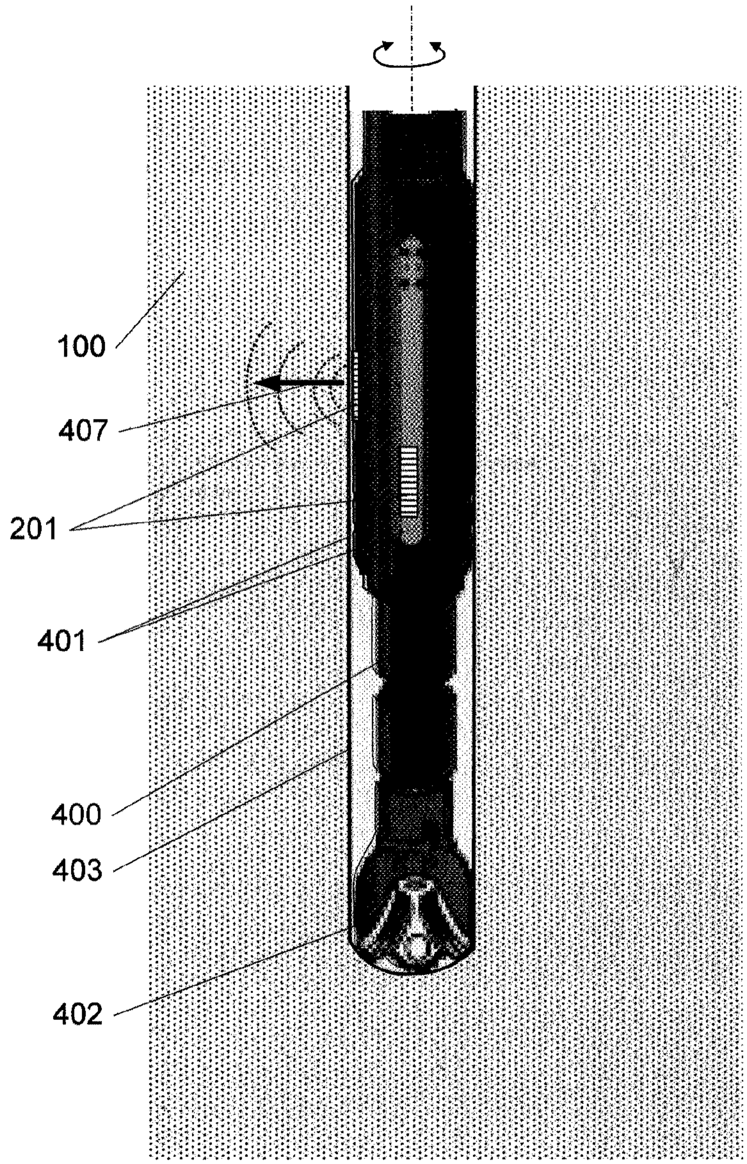


Fig. 5

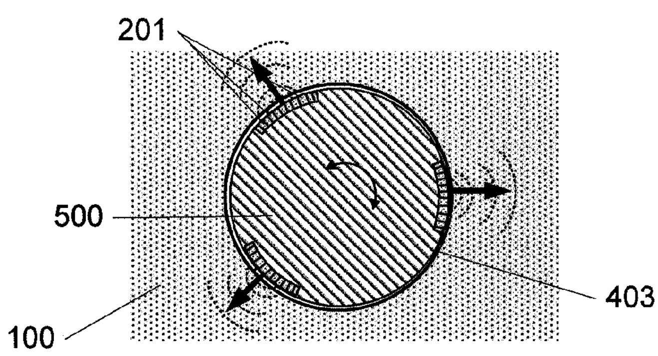
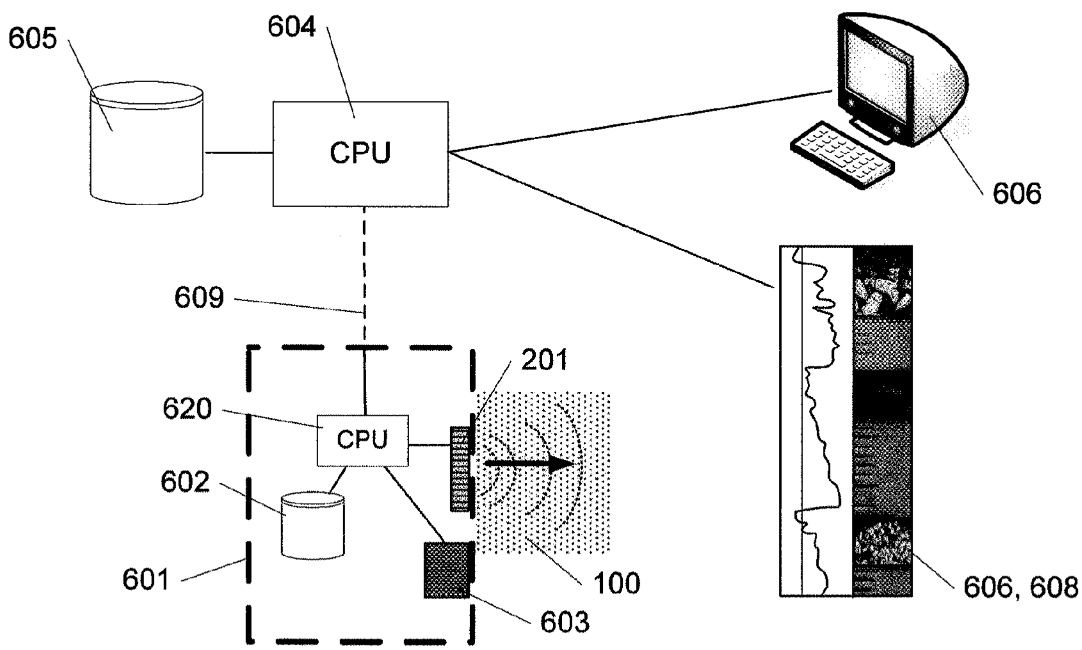


Fig. 6


605
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606
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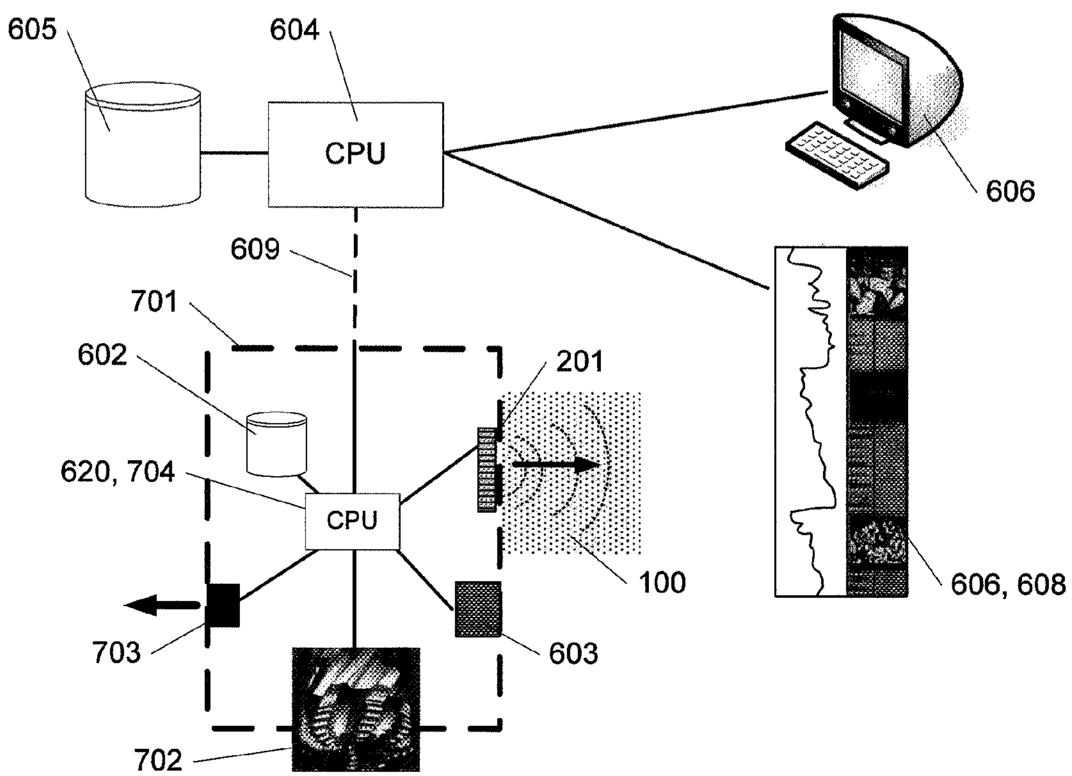
201
620
CPU
602
100
601
603
606, 608

Fig. 7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604
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602
201
620, 704
CPU
100
606, 608
703
603
702

Fig. 8

MEASUREMENTS OF ROCK PARAMETERS

FIELD OF THE INVENTION

[0001] The present invention relates to methods and apparatus to measure physical parameters such as density and porosity of the rock matrix in a near wellbore area as well as the type(s) of fluid present in the near wellbore area.

BACKGROUND

[0002] In geological exploration and development, formation evaluation indicating the physical properties of a volume of rock next to the borehole is used to determine e.g. whether a potential oil or gas field is commercially viable. Extrapolation of the properties beyond the measurement volume further requires a geological model.

[0003] Physical properties of the near wellbore rock are generally evaluated by measurements-while-drilling (MWD), Logging-while-drilling (LWD), by different wireline tools or combinations hereof.

[0004] Measurements-while-drilling (MWD) in general covers the collection of directional data enabling well trajectory description in three-dimensional space while extending the wellbore, and also includes pressure and temperature measurements within the wellbore. Logging-while-drilling (LWD) in general covers the evaluation of physical properties in the matrix surrounding the tools. MWD and LWD are standard practice in offshore directional wells, where the well cost is offset by rig time and wellbore stability considerations. The downhole measured data values are usually stored in solid-state memory, while a low resolution data stream is sent through pressure pulses inside the drill string to surface for real-time measurement readouts. Some MWD/LWD tools have the ability to retrieve the stored data by deploying a wireline tool that engages with the MWD/LWD tools if the data transmission link fails. The latest technology for data transfer further allows for high speed transfer of data from downhole to surface enabling the transfer of large data streams.

[0005] Logging-while-drilling (LWD) covers the measurement of formation properties (e.g. density, resistivity, porosity, sonic velocity, gamma ray) during the excavation of the hole, or shortly thereafter, through the use of tools integrated into the bottomhole assembly. LWD, while sometimes risky and expensive, has the advantage of measuring properties of a formation before drilling fluids invade deeply. Further, many wellbores prove to be difficult or even impossible to measure with conventional wireline tools, especially highly deviated wells where hole stability issues may be time critical. In these situations, the LWD measurement ensures that some measurement of the subsurface is captured in the event that wireline operations are not possible. LWD tools use similar data storage and transmission systems as MWD tools, with some having more solid-state memory to provide higher resolution logs after the tool is tripped out.

[0006] Measurement/Logging-after-drilling covers measurements made by measurements-while-drilling (MWD) tools and logging-while-drilling (LWD) tools subsequent to the initial bit run. MWD logs are recorded while drilling the well. However, these tools can also record logs at later times when the drillstring is in the hole. This may be while pulling out after drilling, or on a subsequent bit run or circulating trip. The latter is also known as re-logging or logging while tripping.

[0007] Electrical wireline is related to any aspect of logging that employs an electrical cable to lower tools into the borehole and to transmit data. A wireline log is hence a continuous measurement of formation properties with electrically powered instruments to infer properties and make decisions about drilling and production related operations. Measurements may include electrical properties (resistivity and conductivity at various frequencies), sonic properties, active and passive nuclear measurements, dimensional measurements of the wellbore, formation fluid sampling, formation pressure measurement, wireline-conveyed sidewall coring tools, and others. In wireline measurements, the logging tool (or sonde) is lowered into the open wellbore and the measurements are preferably and in most cases taken on the way out of the wellbore in order to maintain the tension on the cable as constant as possible for depth correlation purposes. Down log measurements may also be conducted on the way into the well for instance in certain hostile environments where the tool electronics might not survive, and repeated on the way out if possible. Most wireline measurements are recorded continuously while the sonde is moving, however certain fluid sampling and pressure-measuring tools used for formation sampling require that the sonde be stopped, increasing the risk that the sonde or the cable might become stuck. Measurements taken by wireline-logging tools are taken in much the same way as by LWD tools, except that the measurements by the latter are taken by a selfcontained tool near the bottom of the bottomhole assembly and are recorded downward (as the well is deepened) rather than upward from the bottom of the hole (as wireline logs are recorded).

[0008] Two important parameters in defining the type of formation surrounding the borehole are the density and the porosity of the near wellbore rock. These parameters are also applied in combination with resistivity data to detect the fluid type present in the rock matrix, more particularly if hydrocarbon resources (reservoir data) are present. A change of fluid type within the porous volume, i.e. from water to oil or gas results in a dramatic change in the neutron reflection and an increase in the resistivity measurement.

[0009] The conventional measurement technique used in formation evaluation for density and porosity is based on the use of radioactive sources. Live Gamma and Neutron sources are continuously radiating the formation and sensors detect the response (reflection) from the formation. Based on the reflected radiation (and additional data) it is possible to make estimates on the two parameters, density and porosity.

[0010] According to established knowledge all radiation represents a health hazard. The procedure developed and used to load and un-load radioactive sources in Measurement-while-drilling (MWD) Bottom Hole Assembly (BHA) subs are based on three simple rules; "Distance, Shielding and Time of Exposure". To enable the distance long handling rods are used to mount the radioactive source and install/un-install in BHA sub and protective casket (pig). To enable shielding the different sources are stored in "pigs", small containers that are permanently stored in heavy-duty containers. The pig for Gammasources contains substantial mass of lead that prevents the gamma rays from escaping. The pig for Neutron-sources contains water gel, as water is a most suitable reflector for Neutron particles. To enable shortest time of exposure the personnel involved are trained to perform the installation quickly.

[0011] Despite all security efforts performed when applying the method described above employing radioactive sources, the potential health risks as well as the environmental disadvantages of the method provide powerful incentives to develop alternative methods to measure indirectly or directly the rock density and porosity excluding the use of radioactive sources.

[0012] U.S. Pat. No. 6,206,108 discloses a bottom hole assembly comprising a number of sensors adapted to measure different parameters in a wellbore. Different types of sensors are mentioned which utilize different technologies including acoustic, ultra sonic, radioactive devices and many others. Acoustic devices are mentioned in connection with parameters such as porosity and acoustic velocity; however the sensors are also referred to as state of the art sensors. The publication gives no indication that would make a person skilled in the art consider replacing the radioactive based sensors or that it would be desirable to do so.

OBJECT AND SUMMARY OF THE INVENTION

[0013] It is therefore an object of the present invention to present alternative methods and apparatus to measure the density and the porosity of a rock matrix.

[0014] According to one aspect the present invention relates to a borehole tool for performing measurements in a wellbore comprising a number of transducer elements in at least one transducer array placed at an outermost surface of the borehole tool for emitting at least one focused beam of high frequency ultrasound into the rock matrix in the near wellbore area when in use. Hereby is obtained a borehole tool capable of measuring different physical properties of the rock matrix in the near wellbore area, such as for instance densities and porosities. By the use of focused beams of high frequency ultrasound information of the rock matrix of very high resolution is obtainable. These parameters can thus be determined with a far better accuracy and precision than with traditional measuring techniques resulting in better information for finding, evaluating, and exploiting oil and gas fields. The use of ultrasound is also advantageous in making the use of the highly dangerous and polluting radioactive sources superfluous, ultrasound on the other hand posing no risks to the personnel handling or manufacturing the borehole tool or to the environment when in use.

[0015] In one embodiment the at least one transducer array is arranged for close contact with the formation. This is advantageously in that the transducer array is then most of the time in close contact with the wellbore wall and the rock matrix of which the measurements are to be made. The number of boundaries from which the ultrasound beam is reflected is in this way minimized and more precise result obtainable. In one embodiment this can be obtained by placing the at least one transducer array on the ribs or stabilizers of the borehole tool, or in a specifically designed logging tool.

[0016] In further embodiments of the invention the transducer array(s) is placed approximately along the axis of length of the wellbore and/or approximately along the periphery of the tool. Hereby the focal point position of the beam can be controlled and directed to different positions along the length of the wellbore and in a broad range of radial directions from the wellbore, respectively.

[0017] In a further embodiment the transducer array(s) is placed on a sleeve of the borehole tool with a lower rotational speed compared to the drill string. This is advantageously in that measurements can then be made on a stationary or near stationary environment, minimizing dynamic effects, regardless of the motion of the rest of the borehole tool.

[0018] According to an embodiment of the invention the transducer array(s) comprises a fronting material at least partly with similar acoustic impedance as the rock matrix. Hereby is obtained that the reflected energy form hitting the boundary between the fronting material and the rock matrix itself is minimized, and thus, as much energy as possible is transmitted further into the rock.

[0019] In further embodiments the transducer array(s) comprises a fronting material at least partly of a ceramic and/or at least partly of a crystalline structure based on $CaCO_3$. A ceramic is advantageous as a fronting material because of its good properties to resist wear and abrasion in this case arising from the friction between the transducer array and the rock matrix as close contact between the two are desirable for the most accurate measurements. By using a fronting material of a crystalline structure based on $CaCO_3$ similar acoustic impedance between the fronting material and the rock matrix is obtained.

[0020] The invention further relates to a borehole tool according to the above further comprising memory and one or more processors for processing data measured by said transducer array(s). Hereby is obtained a borehole tool where the data from the ultrasound measurements can be stored for as long as needed and possibly transmitted to the surface.

[0021] Also, in one embodiment the borehole tool according to the further comprises a processor for influencing the functional parameters of the transducer array(s) such as frequency, amplitude and/or focal point position of the emitted focused beam. Hereby is obtained a borehole tool where the measuring parameters can be optimized continuously whereby better, more reliable and more precise results can be obtained.

[0022] According to another aspect, the present invention relates to a method for measuring physical parameters of the rock matrix in a near wellbore area comprising the steps of

- **[0023]** from one or more transducer arrays comprising a number of transducer elements and placed on a borehole tool, emitting at least one focused beam of high frequency ultrasound into the rock matrix in the near wellbore area, the beam given a focal point position, frequency and amplitude,
- **[0024]** measuring the amplitude of the reflected signal,
- **[0025]** measuring the time of the largest amplitude in the reflected signal.

[0026] The advantages of this method are as mentioned above for the borehole tool.

[0027] In an embodiment the method according to the above further comprises determining the density of the rock matrix using the laws of reflection. These steps represent a rather simple and fast, yet reliable method capable of determining the rock density with very good precision.

[0028] In an embodiment the method further comprises generating 2D and/or 3D pictures of the formation in the near wellbore area. Hereby pictures of the rock formation in the near wellbore area can be obtained, from which many data can be extracted important for the directioning of the wellbore and possible finding of oil or gas.

[0029] According to another embodiment, the above method comprises determining the porosity of the rock matrix in the near wellbore area from said pictures.

[0030] In a further embodiment the method further comprises emitting series of beams of different focal point positions and/or of different frequencies. By controlling the focal point positions and frequencies, more precise measurements can be obtained and depth based logs can be established.

[0031] In yet a further embodiment the method comprises applying one or more correction filters to generate near perfect focus of the emitted beam. This step also acts to improve the precision of the measured data

[0032] Finally, a further embodiment is a method according to the above further comprising applying Fourier analysis on harmonic frequencies to determine the type of fluid in a porous volume in the near wellbore area. This is an advantageous method to determine for instance if the pores in a rock matrix are gas filled or filled with oil as these materials have different elastic properties. The type of formation and eventually its commercial value is in this way better determined.

[0033] The term "high frequency ultrasound" as use in connection with the present invention refers to ultra sound with a frequency in the range of 1-100 MHz, more desirable 1-20 MHz and preferably 1-10 MHz. The selection of a suitable frequency range will as explained herein depend on the desired resolution and the level of acceptable damping.

BRIEF DESCRIPTION OF THE DRAWINGS

[0034] In the following, preferred embodiments of the invention will be described referring to the figures, where

[0035] FIG. **1** illustrates some basic principles of ultrasound emission used in the invention,

[0036] FIG. **2** illustrates the principle of a time delayed focused beam,

[0037] FIG. **3** illustrates an array of transducer elements emitting an interference wave with adjustable lateral focus and focus depth,

[0038] FIG. **4** illustrates a method of determining the density and porosity of a material according to one embodiment of the invention,

[0039] FIG. **5** shows a borehole assembly with ultrasound transducers mounted on the ribs,

[0040] FIG. **6** shows in a cross-sectional view one embodiment of a number of peripherical transducer arrays mounted on a borehole assembly according to one embodiment of the present invention, and

[0041] FIGS. **7** and **8** show two different embodiments of systems for determining the formation parameters according to the invention.

DESCRIPTION OF EMBODIMENTS

[0042] The present invention is based on the principle idea of the application of ultrasound to evaluate formation parameters in the near wellbore rock.

[0043] In the context of borehole logging, ultrasonic measurements have—apart from technology development projects to measure flow by use of ultrasound Doppler frequency shift—traditionally only been applied in instruments of the simple pulse-echo type where an acoustic pulse reflected from the front and the back of the borehole casing is measured and analyzed to obtain a value of the thickness and the quality of the borehole wall itself. This technique is for example used in borehole televiewers and in various cased-hole devices to determine the casing corrosion and cement-bond quality. The acoustic signals are here in the hundreds of kilohertz to the low-megahertz range, i.e. of very low frequencies compared to the ultrasound methods according to the present invention as will be apparent below.

[0044] Specifically, the application of ultrasound for formation evaluation purposes, utilizing the benefits of high frequency ultrasound has not been investigated in prior art.

[0045] The basic physical behavior of an acoustic wave being sent out through a heterogeneous medium or an object is illustrated in FIG. **1**. An acoustic pulse is emitted from a transducer probe **102** transforming an electrical signal into mechanical vibrations and vice versa. The transducer can be made of piezoelectric crystals or a ferromagnetic material. In general, the same transducer can be used both to send and receive sound waves. Generally, a transducer probe also has a sound absorbing substance to eliminate back-reflections from the probe itself. Special embodiments of transducers for use in the present invention are discussed later.

[0046] When a wave front **101** is traveling through a medium **100**, dampening (attenuation), reflection, and transmission will take place governed by acoustic laws. Basically, ultrasound measuring is performed by emitting a pulse **104**, which will be partly reflected **105** from any boundaries **103** between different structures or phases in the medium **100**, and partially transmitted **106**. The reflection **105** and transmission **106** depend on the difference in the acoustic impedance of the two structures. Further, the sound wave to some extend is dampened or attenuated on its way through the different matters. The signal dampening is a function of the traveled wavelength, wherefore high frequency reduces the depth of investigation. The application of ultrasound is thus a trade-off between the benefits of high frequencies and depth of penetration.

[0047] The acoustic impedance Z is the product of the density ρ and the acoustic velocity v (speed of sound in the material) and is a physical property of all defined masses, Z=ρ v. The relationship between the reflected energy and the transmitted energy from any matter boundary between two materials with the impedances Z_1 and Z_2 is well known and defined through the following equations:

$$R = \left(\frac{Z_2 - Z_1}{Z_2 + Z_1}\right)^2 \tag{1}$$

$$T = 1 - R = 1 - \left(\frac{Z_2 - Z_1}{Z_2 + Z_1}\right)^2 \tag{2}$$

[0048] Here R is the fraction of reflected amplitude and T is the fraction of the transmitted amplitude, with reference to the original amplitude.

[0049] When the pulse returns to the transducer **102**, the reflected pulse **105** from some boundary gives information of two measurements: The amplitude of the reflected signal, which is dependent on the amplitude of the transmitted signal and the attenuation of the matrix (the matrix being the material or combination of material from a transducer and into the measuring point/point of focus), and the time it takes returning, which is dependent on the distance from the transducer and the speed of sound in the matrix.

[0050] Advantageous transducer probes for the present invention can be of many shapes and sizes. The shape of the probe determines its field of view, and the frequency of emitted sound waves determines how deep the sound waves penetrate and the resolution of the image. Transducer probes may contain one or more piezo-crystal or ferromagnetic elements in one or more phased arrays. In multiple-element probes, each element generally has its own circuit. The transducers may for example be placed in a ring form or as a stack of similarly shapes transducer elements.

[0051] Multiple-element probes have the great advantage that the ultrasonic beam can be "steered" by changing the timing in which each element gets pulsed. This is illustrated in FIG. **2**. Here a number of transducer elements **102** are stacked in a transducer array **201**. If all the transducer elements **102** are 'pinged' or stimulated at the same time the result would be an unfocused beam with acoustic energy spreading out along several focus lines. By stimulating the transducer elements **102** in a rapid sequence, the ultrasound is sent out in an interference pattern **120**. According to Huygens principle, the wavefront will behave as a single beam, thus the beam is formed by all transducers in the array, and the direction is determined by the time sequence. The same principle of phase steering can be applied to make a concave wavefront, resulting in focusing of the beam with its narrowest part (the focal depth point) a distance (focal depth) **121** from the probe. By regulating the time delay of the element pulses both the focus depth and optionally the lateral position of the focus can be changed as illustrated in FIG. **3**. The time-delayed pulses are emitted from a transducer array penetrating into a medium **100**. The acoustic focus **202** of the resulting interference wave **205** is changed in lateral position **203** (to the left in the figure) and in depth **204** (to the right) by controlling the time sequences and time delay by which the pulses are emitted.

[0052] Alternatively, an acoustic focus can also be obtained by the geometrically shape and design of the array of transducer elements for instance by a curved transducer array.

[0053] The main energy (biggest amplitude) in the reflected wave has the same frequency as the original wave, in addition to the harmonic oscillations (typically $3\times f_1$, $5\times f_1$) that are present in an acoustically unlinear matrix. This means that when an acoustic wave with f_1 Hz is sent through a media striking an object, the reflected signal will contain a fraction of the output energy at different significant frequencies—f Hz, f_1, $3\times f_1$ Hz, $5\times f_1$ Hz, etc. This physical phenomenon is used when scanning with a focused beam as described above in the heterogeneous rock matrix (solids, fluids), where mathematical analysis on f, f_1, $n\times f_1$ is then applied to determine the heterogeneous media (n=3, 5, 7 etc). In traditional use of ultrasound a single frequency is used for the transmitting and receiving signal in order to generate an adequate acoustic image. However, if the matrix has acoustically unlinear properties Fourier transformation of the amplitude vs. time signal may be applied to filter out the harmonic frequencies. This enables different acoustic images generated from the transmitted frequency and the harmonic frequencies. Images generated from the harmonic frequencies will have less aberration in signal, as the signal has only traveled one way in the matrix compared to two ways for the transmitted frequency. Images created from harmonic frequencies will generally have less amplitude, but more importantly the images will be less disturbed from changes in velocity in the traveled matrix.

[0054] FIG. **4** illustrates a method of determining the density of a rock matrix according to one embodiment of the invention. Pulses of ultrasound frequencies (>1 MHz) are sent from an array of transducer elements in a transducer array thereby emitting an interference wave with a given focus in a chosen position (lateral position and depth) relative to the transducer, with a known amplitude A and at a known frequency f_1, **301**. The transducer array is placed as close as possible to the rock wall and the rock matrix in the near wellbore area is scanned, **302** for instance by swiping along the z-axis of the wellbore (along the wellbore) or in different radial directions for the same or similar depths in the borehole. The optimal scanning or swipe pattern would depend on the actual configuration of the transducer array(s) on the borehole tool. Assuming a homogeneous rock matrix on a microscale, one would only need a small swipe to define the density and the porosity.

[0055] The amplitude of the reflected signal R relative to the emitted amplitude along with the time of the largest amplitude in the reflected signal is then measured, **303**. As the impedance Z_1 is known (known ρ_1 and v_i), the laws of reflection (equation (1) and (2)) yield the impedance of the rock matrix Z_2. Furthermore, by assuming that the highest amplitude returns from the depth of focus (with a known position), the velocity of sound in the rock v_2, **304** is determined. Combining these, gives the density of the rock matrix ρ_2 as a mean value of density over the distance into the focal point. The measurements can then be repeated for a number of different focal point positions and over a range of different frequencies f_1, **306**, whereby more accurate results can be obtained and a depth based log may be established.

[0056] As all boundaries or interfaces cause some reflections of the ultrasound and thus a spreading of the energy, the focal point will to some extend be smeared out or blurred. The best measurements and most accurate results with the above described method are hence obtained when the transducer array is in close contact with the rock wall with no mud or fluid in between. On the other hand, if this is not the case, the matrix in between the probe and the rock wall (some mud and fluid with moving particles) would then have to be taken into consideration in the above method. In some cases the acoustic impedance value of the matrix between the sensor and the rock matrix is known. Alternatively, the calculation can be based on estimated values for the physical parameters of the mud.

[0057] The high frequency ultrasound is furthermore capable of generating high resolution images employing known techniques and methods from e.g. medical ultrasound scanning. Here, the 2D images **307** are obtained e.g. by plotting the relative amplitude of reflected signals at the points from where they are reflected. Stacking 2D images **307** from approximately stationary objects together, 3D images of very high resolution revealing some or all internal boundaries can be extracted from the scanning data of a matter e.g. by application of known image processing techniques. According to the present invention the same or similar techniques can be used on the ultrasound scanning data from the near wellbore rock to get 2D and/or 3D pictures of the formation of the rock. From these the porosity of the rock matrix can then be determined, **305**, using standard mathematical expressions.

[0058] The higher the frequencies of the transmitted pulses are, the more information can be extracted about the inhomogenities of the rock matrix, i.e. grain particles, pores etc. The following definitions of grain sizes are commonly used within drilling (source: Drilling Data Handbook, Institut Francais du Petrole Publications):

[0059] Clay/Mudstone: <4 micrometer

[0060] Silt: 4 micrometer—62.5 micrometer

[0061] Sandstone: 62.5 micrometer—2 mm (ranging from very fine to coarse sandstone)

[0062] Conglometares (granules, gravel, pebbles): >2 mm

[0063] Targeting sandstone as the primary rock matrix of interest, the smallest grain size is $6.25*10^{-4}$ m. Equation (3) gives the relationship between frequency f, wave length λ and speed of sound v:

$$f = \frac{v}{\lambda} \tag{3}$$

[0064] Assuming a speed of sound, v, in sandstone of 2900 m/s and assuming that wave length must be at the same length as the grain size in order to achieve absolute porosity measurements, the following calculation can be made:

$$f = v/\lambda = 2900\ \text{m/s}/6.25*10^{-4} = 4.6\ \text{MHz}$$

[0065] Better acoustic images may be created by increasing the transmitting frequency, for example corresponding to a wave length that is 1/10 of the grain size. This would impose a frequency of 46 MHz.

[0066] In a further embodiment of the invention the ultrasound measurements are used to determine the types of fluid present in the porous volumes of the rock matrix in the near wellbore area. This is done by scanning the rock matrix with a range of different ultrasound frequencies and analyzing the reflected harmonic frequencies applying Fourier transformations. As different fluids such as oil, gas or water have different elastic properties they also have different resonance frequencies influencing the reflected signal differently. Being un-linear matter, water and oil or gas will be reflecting harmonic frequencies that are reflected with a phase shift compared to the reflected signal from the rock material itself (assumed to be unlinear). Thus, applying Fourier analysis on the measured reflected harmonic frequencies from a series of different emitted frequencies yields a picture of the elasticity of the fluid within a certain pore which in turn reveals information on the type of fluid.

[0067] The challenge with increasing the frequency is, as also mentioned earlier, that signal dampening is a function of traveled wavelength, meaning that high frequency reduces the depth of investigation. Frequencies used in conventional medical ultrasound range typically from 1-8 MHz, but transducer probes emitting ultrasound in the GHz-range have been developed. The optimal frequency to use downhole in the investigation of the near wellbore matrix is hence a question of trade-off between obtainable resolution (precision of results) and possible penetration depth. Different types of transducers of different frequencies should thus be chosen according to the present situation, the task at hand, the necessity of highly accurate data or just indicative, the memory or processor capacity etc.

[0068] Another aspect of the ultrasound measurements is how the focused beam is disturbed when the acoustic energy passes through the heterogeneous rock matrix. In order to account for this, different filters may be applied to generate near perfect focus, such as for instance iterative aberration correction filters. The principle is here to use harmonic frequency signals (returning signal) and compare this with the returning signals at the transmitting frequency. The harmonic frequency signals have traveled one direction. The transmitting frequency signal has traveled back and forth (two directions). Investigating phase shifts enables a description of the velocity change in the matrix from the transducer to the focus depth. By adding an inverted phase shift to the transmitted signal, it is possible to cancel out the time delay given by the heterogeneous matrix (different speed of sound in one matrix). By performing this iteratively a close to perfect focus is achievable.

[0069] As mentioned, the acoustic energy hitting a matter boundary is divided into reflected and transmitted energy. As can be read from the equations (1) and (2) above, if the acoustic impedance in two materials is similar, very little energy is reflected. This is why gel based on water, is commonly used between the probe face and the body during medical exterior examination, as water and beef reveal similar impedances (our body consists of 50-70% of water). Hence, according to one aspect of the present invention, a fronting material of similar acoustic impedance as the rock matrix is applied in the ultrasound transducers. As an example a sandstone with v=2900 m/s and density of 2200 kg/m^3 would have an acoustic impedance of $6.38*10^6$ kg/m^2s. For measurements on a rock matrix with a lot of sandstone a fronting material with a crystalline structure (based on $CaCO_3$) may be designed with matching acoustic impedance as sandstone. One should notice that a piece of sandstone is porous wherefore the acoustic impedance for a porous matrix is not really valid/possible to define, since the main volume would be sandstone and the remaining void would be filled with fluid/gas with different (lower) acoustic impedance. Therefore an exact match between the acoustic impedance of the fronting material of the transducer array and the rock matrix is probably not possible except by a mere chance, however, similar properties should be aimed towards in order to obtain the most accurate results.

[0070] As high frequency ultrasound is subject to amplitude dampening it is important to have minimal or preferably direct contact between the transducer elements and the formation. Therefore according to one embodiment of the invention, the transducer elements **201** (enlarged for clarity) are mounted on stabilizers or the ribs **401** of a rotary steerable assembly **400**, as sketched in FIG. **5**. Examples of such assemblies are the PowerDrive from Schlumberger or AutoTrak from Baker Hughes Inteq. The ribs **401** apply force against the borehole wall **403** and are in direct contact with the rock matrix **100**. An advantage of placing the transducer arrays close to the drill bit **402** is that the measurements will then be performed on the rock formation before the drilling fluids invade deeply and thus the measurements will only be inflicted by mudcake or mud particles in the rock formation to a very limited extent.

[0071] For single measurements transducer elements **201** may be mounted on the front of probes of formation testers. For wireline applications the transducer elements **201** may be applied in the probe of tools an example of which is the Schlumberger's MDT. Of course, the transducer arrays may also according to a further embodiment of the invention be placed in their own borehole tool together with all relevant electronics. In all cases, one or more arrays of transducer elements are mounted on the outermost parts of the borehole equipment in order to minimize the distance to the rock matrix **100** into which the transducer emits the ultrasound as sketched by the wave and the arrow **407** in FIG. **5**. Therefore the transducer arrays are advantageously equipped with a fronting material with very good wear and abrasion resisting properties. In one embodiment the fronting material is made of a ceramic. A number of ultrasound transducers may be used in accordance with the design of the specific drilling or wireline tool, such as for instance one on each rib approximately along the axis of length of the wellbore or one or a number of curved arrays of transducer elements extending around the periphery of the tool. The latter is illustrated in FIG. **6**. This configuration is advantageous in that measurements are obtainable at a broad range of radial directions from the wellbore, almost regardless of the rotational speed of the equipment **500**. The transducer array(s) may further be mounted on a sleeve on the borehole assembly rotating slower than the rest of the assembly, say 2-3 rotations per hour. Hereby is obtained that the measurements can be made on a near static environment where dynamic effects can be disregarded and more accurate results obtained.

[0072] In FIG. **7** is shown a system for measuring the formation parameters of a near wellbore area by the use of ultrasound and according to one embodiment of the invention. The system comprises a local system **601** which is placed in the borehole logging or drilling tool. This local system comprises firstly one or more transducer arrays **201** for emitting ultrasound into the rock matrix **100**. The transducer arrays **201** are via a local processor **620** connected to a local memory **602** for storing the measured data from the ultrasound measurements. If the tool is purely a logging tool only registering and measuring formation parameters and with no feed-back or control mechanisms, no more system parts need be present in the downhole tool. In one embodiment the local system, however further comprises one or more sensors **603** for registering parameters such as for instance the time, the position, temperature, and/or the velocity of the tool etc. Hereby a more complete and accurate log **608** of the borehole is obtainable.

[0073] In a further embodiment, the local system comprises a local processor **620** for processing some of the measured data which is then used e.g. to adjust some parameters in the following measurements. For example for use in an iterative adjustment of the frequency range applied in the ultrasound measurements for better correlation with the rock matrix. Alternatively the obtained data may at some times (but not necessarily at all times) be transmitted **609** to a main processor (CPU) **604** and a main memory **605** on the surface in a high speed telemetry system and processed on the surface. A high speed telemetry system is preferable, since detailed acoustic processing requires large amounts of data to be transferred from/to the transducers. Alternatively the transmission may also take place more or less continuously by wireline and/or when tripping the tool. The CPU performs the calculations involved in processing the data,—for instance determining the densities and porosity according to the methods described earlier,—and presents the measurements, images and results **606**, **608** on e.g. a monitor, a printer or the like. The CPU can also store the processed data and/or image on disk or on the main memory **605**.

[0074] A more enhanced closed loop system for formation evaluation and exploitation is sketched in FIG. **8**. Here, in comparison with the system described in FIG. **7**, the system further gives the possibility of using the measured and calculated formation parameters directly to control or influence the drilling or general behavior of the tool. As in the previous embodiment, the local system here **701** also comprises an ultrasound transducer **201**, a local processor **620**, a local memory **602** and advantageously one or more sensors **603**. In addition hereto a local processor **704** in the local system **701** is capable of extracting at least some of the formation parameters based on pre-loaded data and the measured data from the transducer and the sensor(s). In this embodiment these processed data are used directly in controlling and/or regulating the behavior of the borehole tool. This could for instance be by regulating the rate of penetration (ROP) **702** or by regulating the direction of drilling (as illustrated by the force unit **703**. As in the previous embodiment, the local system **701** is coupled to a further processor **604** and a main memory **605** outside the borehole. The data transmission link **609** may also transmit data the other way from the main processor **604** down to the local system so that a person may influence and control the different units in the logging and/or drilling tool. Autopilot system as this where the automatic steering to some extend or completely is based on certain sensor values is used today in some Rotary Steerable Drilling systems. One drawback of such a closed loop systems is the risk of a sensor which might set off the drilling in a wrong direction with the result of several days of non-productive time spent on side-tracking. On the other hand, given that all relevant sensors and processors work as planned, the system is advantageous in giving the possibility to correct and direct the drilling of the borehole tool faster and more accurately based on the just measured and calculated rock parameters thereby increasing the chances of a more profitably drilling.

[0075] Definitions:

[0076] Formation:

[0077] "Formation" is a general term for the rock around the borehole. In the context of formation evaluation, the term refers to the volume of rock seen by a measurement made in the borehole, as in a log or a well test. These measurements indicate the physical properties of this volume. Extrapolation of the properties beyond the measurement volume requires a geological model.

[0078] Porosity:

[0079] "Porosity" is the percentage of pore volume or void space, or that volume within rock that can contain fluids. Porosity can be a relic of deposition (primary porosity, such as space between grains that were not compacted together completely) or can develop through alteration of the rock (secondary porosity, such as when feldspar grains or fossils are preferentially dissolved from sandstones). Effective porosity is the interconnected pore volume in a rock that contributes to fluid flow in a reservoir. It excludes isolated pores. Total porosity is the total void space in the rock whether or not it contributes to fluid flow. Thus, effective porosity is typically less than total porosity.

[0080] It should be noted that the above-mentioned embodiments illustrate rather than limit the invention, and that those skilled in the art will be able to design many alternative embodiments without departing from the scope of the appended claims. In the claims, any reference signs placed between parentheses shall not be construed as limiting the claim. The word 'comprising' does not exclude the presence of other elements or steps than those listed in a claim.

1. A borehole tool for performing measurements in a wellbore comprising a number of transducer elements in at least one transducer array placed at an outermost surface of the borehole tool for emitting at least one focused beam of high frequency ultrasound into the rock matrix in the near wellbore area when in use.

2. A borehole tool according to claim **1**, where said at least one transducer array is arranged for close contact with the formation.

3. A borehole tool according to claim **1**, where said at least one transducer array is placed on the ribs or stabilizers of the borehole tool.

4. A borehole tool according to claim **1**, where said at least one transducer array is placed approximately along the axis of length of the wellbore.

5. A borehole tool according to claim **1**, where said at least one transducer array is placed approximately along the periphery of the tool.

6. A borehole tool according to claim **1**,where said at least one transducer array is placed on a sleeve of the borehole tool with a lower rotational speed.

7. A borehole tool according to claim **1**, where said at least one transducer array comprises a fronting material at least partly with similar acoustic impedance as the rock matrix.

8. A borehole tool according to claim **1**, where said at least one transducer array comprises a fronting material at least partly of a ceramic.

9. A borehole tool according to claim **1**, where said at least one transducer array comprises a fronting material at least partly of a crystalline structure based on $CaCO_3$.

10. A borehole tool according to claim **1** further comprising memory and one or more processors for processing data measured by said at least one transducer array.

11. A borehole tool according to claim **1** further comprising a processor for influencing at least one of the functional parameters of the at least one transducer array selected from the group consisting of: frequency, amplitude and focal point position of the emitted focused beam.

12. A method for measuring physical parameters of the rock matrix in a near wellbore area comprising the steps of

from one or more transducer arrays comprising a number of transducer elements and placed on a borehole tool, emitting at least one focused beam of high frequency ultrasound into the rock matrix in the near wellbore area, the beam given a focal point position, frequency and amplitude,

measuring the amplitude of the reflected signal,

measuring the time of the largest amplitude in the reflected signal.

13. A method according to claim **12** further comprising determining the density of the rock matrix using the laws of reflection.

14. A method according to claim **12** further comprising generating 2D and/or 3D pictures of the formation in the near wellbore area.

15. A method according to claim **14** further comprising determining the porosity of the rock matrix in the near wellbore area from said pictures.

16. A method according to claim **12** further comprising emitting series of beams of different focal point positions.

17. A method according to claim **12** further comprising emitting series of beams of different frequencies.

18. A method according to claim **12** further comprising applying one or more correction filters to generate near perfect focus of the emitted beam.

19. A method according to claim **12** further comprising applying Fourier analysis on harmonic frequencies to determine the type of fluid in a porous volume in the near wellbore area.

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