METHOD AND APPARATUS FOR CONTINUOUS FORMATION SAMPLING AND ANALYSIS DURING WELLBORE DRILLING

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ABSTRACT

A wellbore formation sample acquisition and analysis instrument includes an annular drill bit configured to couple to one end of a drill string. The bit defines a passageway extending from a cutting face thereof to an exterior surface at a longitudinally spaced apart position from the cutting face. The instrument includes at least one sensor configured to measure a selected parameter of a sample of subsurface formation urged into the passageway by action of the cutting face against subsurface formations. Samples of the subsurface formations are ejected from the exterior surface end of the passageway by the samples entering the cutting face end thereof.
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BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention
[0002] The invention relates generally to the field of wellbore drilling and formation evaluation. More particularly, the invention relates to devices for extracting samples of subsurface formations during drilling of a wellbore and analyzing such samples with respect to various physical parameters during wellbore drilling.
[0003] 2. Background Art
[0004] Wellbore drilling through subsurface Earth formations is performed, for among other purposes, to provide a hydraulic path from subsurface reservoirs to the Earth's surface. During the drilling of such wellbores various instruments are inserted into the wellbore, either during drilling or shortly thereafter, that make measurements of various petrophysical properties of the subsurface formations. Such measurements may include, for example, electrical conductivity, acoustic compressional velocity and shear velocity, neutron slowing down length and related parameters, natural gamma radiation, density, and longitudinal and transverse nuclear magnetic resonance relaxation properties.
[0005] The foregoing measurements may be used to estimate the amount of hydrocarbons in place in various subsurface reservoirs, and to estimate the amount of and rate at which hydrocarbons may be produced from such reservoirs. It is known in the art to take samples of subsurface formations for the purpose of making more direct measurements of certain physical properties of the formations, for example, porosity, permeability, and capillary pressure behavior. Such properties are related to the structure of the void spaces of the various formations and are not readily susceptible to determination by the indirect measurements described above without actual formation samples to establish relationships between the foregoing properties and the previously described petrophysical measurements.

[0006] One technique for obtaining samples of the subsurface formations is called "coring." Coring is typically performed using a specialized drill bit, that has an annular drilling surface rather than one that occupies the full cross section of the forward or cutting face of the bit. The annular bit leaves a centrally disposed cylinder of rock formation as it drills the wellbore. In a coring system, the cylinder of rock formation is moved, as drilling progresses, into a non-rotating barrel or sleeve inside a drill string used to rotate the drill bit. Once the barrel is full of core sample, it is typically retrieved from the wellbore. Various core barrels have been devised that may be retrieved without removing the entire wellbore drilling assembly or "string" from the wellbore. Such retrievable barrels can substantially reduce the time needed to obtain core samples, because replacement of the core barrel with an empty one may be performed, for example, by lowering and retrieving an electrical cable or slickline inside the drill string to retrieve the full core barrel and replace it with an empty one so that coring can continue. One such coring system is described, for example, in U.S. Pat. No. 7,124,841 issued to Wada, et al.

[0007] As mentioned above, it is known in the art to perform coring concurrently with making LWD measurements. A system and method for performing such functions are described, for example, in U.S. Pat. No. 7,168,508 issued to Goldberg, et al. An advantage purportedly offered by the device shown in the Goldberg, et al., patent is to assure that the depth of rock formation samples obtained by coring is accurately correlated to the depth at which the various LWD measurements are made. It is also possible using such system to select core depths, and to avoid changing drill strings to include core bits where an ordinary "full cross section" bit had been used during LWD operations when the desired core depth is reached.

[0008] It is also known in the art to make measurements on the core samples themselves during the drilling thereof. U.S. Pat. No. 5,984,023 issued to Sharma, et al., describes a core drilling system in which the core sample is moved past one or more sensors in order to make petrophysical measurements of the core sample while it is being drilled. The measurements made by the sensor(s) may be stored in a data storage device in the instrument while it is in the wellbore, and/or some of the measurements may be transmitted to the Earth's surface using a form of telemetry in which pressure of drilling fluid ("drilling mud") in the wellbore is modulated, such telemetry being known in the art as "mud pulse telemetry." Making measurements of petrophysical properties on core samples shortly after they have been drilled and while still at wellbore environmental conditions may provide the advantages of more precise measurements relating to the core structure and native fluid content of the subsurface formations.

[0009] In all of the foregoing coring methods, it is necessary to remove the core barrel after it is filled with core sample. However the core barrel is removed and replaced, e.g., whether by wireline or by removing the drill string from the wellbore, it is necessary to interrupt the drilling process to retrieve and/or replace the core barrel. Such interruption can be time consuming and therefore costly, and particularly in the case of wireline core barrel retrieval, can risk having the drill string become stuck in the wellbore.

[0010] There exists a need for a formation sampling and formation sample analysis method and device that does not require interruption of drilling.

SUMMARY OF THE INVENTION

[0011] A wellbore formation sample acquisition and analysis instrument according to one aspect of the invention includes an annular drill bit configured to couple to one end of a drill string. The bit defines a passageway extending from a cutting face thereof to an exterior surface at a longitudinally spaced apart position from the cutting face. The instrument includes at least one sensor configured to measure a selected parameter of a sample of subsurface formation urged into the passageway by action of the cutting face against subsurface formations. Samples of the subsurface formations are ejected from the exterior surface end of the passageway by the samples entering the cutting face end thereof.

[0012] Other aspects and advantages of the invention will be apparent from the following description and the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] FIG. 1 shows an example drilling system with which the invention may be used.
An example wellbore drilling system is shown in FIG. 1 and includes an example of a formation sample acquisition and analysis device according to the invention. A drilling rig 24 or similar lifting device suspends a conduit called a “drill string 20” within a wellbore 18 being drilled through subsurface Earth formations 11. The drill string 20 may be assembled by threadedly coupling together end to end a number of segments (“joints”) 22 of drill pipe. The drill string 20 may include a formation sample-taking drill bit 12 at its lower end. Particular features of the drill bit 12 will be further explained with reference to FIG. 2. When the drill bit 12 is axially urged into the formations 11 at the bottom of the wellbore 18 by the applying some of the weight of the drill string 20, and when it is rotated by equipment (e.g., top drive 26) on the drilling rig 24, such urging and rotation causes the bit 12 to axially extend (“deepen”) the wellbore 18 by drilling the formations 11. As will be explained with reference to FIG. 2, such drilling may enable acquiring a sample of the formations 11 as a result of such drilling. The lower end of the drill string 20 may include, at a selected position above and proximate to the drill bit 12, a sample analysis unit 10. The sample analysis unit 10 may include one or more sensors (FIG. 2) for measuring selected properties of a formation sample (FIG. 2) passed therethrough by the action of the drill bit 12. The one or more sensors (FIG. 2) in the sample analysis unit 10 may be coupled to a telemetry transmitter or transceiver (FIG. 2) to communicate the measurements to the Earth’s surface along an electrical and/or optical conductor (not shown) in the drill string 20. Proximate its lower end, the drill string 20 may also include an MWD instrument 14 and an LWD instrument 16 of types well known in the art.

During drilling of the wellbore 18, a pump 32 lifts drilling fluid (“mud”) 30 from a tank 28 or pit and discharges the mud 30 under pressure through a standpipe 34 and flexible conduit 35 or hose, through the top drive 26 and into an interior passage (not shown separately in FIG. 1) inside the drill string 20. The mud 30 exits the drill string 20 through courses or nozzles (FIG. 2) in the drill bit 12, where it then cools and lubricates the drill bit 12 and lifts drill cuttings generated by the drill bit 12 to the Earth’s surface. Some examples of MWD instrument 14 or LWD instrument 16 may include a telemetry transmitter (not shown separately) that modulates the flow of the mud 30 through the drill string 20. Such modulation may cause pressure variations in the mud 30 that may be detected at the Earth’s surface by a pressure transducer 36 coupled at a selected position between the outlet of the pump 32 and the top drive 26. Signals from the transducer 36, which may be electrical and/or optical signals, for example, may be conducted to a recording unit 38 for decoding and interpretation using techniques well known in the art. The decoded signals typically correspond to measurements made by one or more of the sensors (not shown) in the MWD instrument 14 and/or the LWD 16 instrument, and may, in some examples, include measurements made by the analysis unit 10. In the present example, such mud pressure modulation telemetry may be used in conjunction with, or as backup for an electromagnetic telemetry system including wired drill pipe.

An electromagnetic transmitter (not shown separately) may be included in the either or both the sample analysis unit 10 and LWD instrument 16, and may generate signals that are communicated along electrical conductors in the wired drill pipe. One type of “wired” drill pipe, as mentioned above in the Background section herein, is described in U.S. Patent Application Publication No. 2006/0225926 filed by Madhavan, et al., and assigned to the assignee of the present invention. A wireless transceiver sub 37A may be disposed in the uppermost part of the drill string 20, typically directly coupled to the top drive 26. The wireless transceiver 37A may include communication devices to wirelessly transmit data between the drill string 20 and the recording unit 38, using a second wireless transceiver 37B associated with the recording unit. In another example, a drilling rig may include a wired surface communications device between wired drill pipe and the recording unit 38.

An example drill bit and sample analysis unit combination is shown in cut away view in FIG. 2. The drill bit 12 may be a fixed cutter bit, in which cutting elements 12B each of which includes a polycrystalline carbide compact (PDC) cutter bonded to a cutting structure to form the cutting element 12B. Each cutting element 12B may then be affixed to a bit body 12A. The bit body 12A may be made from matrix material including tungsten carbide and a binder alloy according to materials and processes well known in the art, or can be made from steel or other high strength metal. The bit body 12A includes a sample receiving passageway 12D located substantially coaxially with the center line or rotational center (not shown) of the bit 12. As explained with reference to FIG. 1, as the bit 12 cuts through the formations 11 in FIG. 1, a cylindrical “plug” or sample of the formation remains undrilled and is urged into the passageway 12D by the action of the bit 1 against the lowermost face of the formations 11 in FIG. 1. The bit body 12A may include courses 12F for movement of the drilling mud (30 in FIG. 1) therethrough outward into the wellbore through jets or nozzles 12C as is well known in the art.

The sample analysis unit 10 may in some examples, such as shown in FIG. 2, be disposed in a separate housing 10A that threadedly couples at a lower end 10D thereof to mating thread 12E in the bit body 12A. The housing 10A may include a corresponding threaded coupling 10C at the other longitudinal end for connection to the drill string (20 in FIG. 1). In the present example, the sample analysis unit 10 can be configured to operate with wired drill pipe of the kind explained above with reference to FIG. 1, and can include a communication device 42 such as a toroidal transformer disposed in a groove 10E in a thread shoulder on the upper threaded coupling 10C. An example of such communication device, as stated above, is described in U.S. Patent Application Publication No. 2006/0225926 filed by Madhavan, et al., and assigned to the assignee of the present invention. In another example, the sample analysis unit 10 may be formed integral with the drill bit 12, instead of using a separate sub, as shown in FIG. 2A.
The passageway 12D in the bit 12 is coupled at the end opposite the cutting face of the bit to one end of a corresponding passageway 10F in the housing 10A. In the present example, the passageway 10F is disposed at the bit end substantially coaxial with the passageway 12D in the bit body 12A to form a continuous passageway for receiving samples of the formations as the wellbore is drilled. The passageway 10F in the housing 10A may gradually expand in internal diameter from the bit end to the exit 40, to reduce the possibility that samples of the formation could become stuck in the orifice. Such sticking would reduce the effectiveness of the drill bit 12 in extracting samples of the formation for analysis.

Analysis of the samples may be performed in the sample analysis unit 10 by one or more sensors 48, 44, 46 disposed inside the housing 10A, proximate the orifice 10F. Such sensor(s) are configured to measure one or more selected properties of the rock samples disposed proximate the sensor(s). Examples of suitable types of sensors are described in U.S. Pat. No. 5,984,023 issued to Sharma, et al., and incorporated herein by reference. Measurements made by the various sensors 44, 46, 48 may be transferred to a telemetry transceiver 50. The signals may then be transferred to the communication device 42 for transmission to the Earth's surface as explained with reference to FIG. 1. Alternatively, or in addition thereto, the signals may be transferred to a device (not shown in FIG. 2) for communication to the Earth's surface using mud pressure modulation telemetry of any type known in the art.

Non-limiting examples of the types of sensors that may be used include: electrical resistivity sensors, both of the galvanic and electromagnetic induction type; acoustic velocity sensors, both compression and shear; capacitance sensors; density sensors; neutron porosity and/or capture cross-section sensors; natural gamma radiation and/or neutron activation gamma radiation sensors; nuclear magnetic relaxometry and/or spectroscopy sensors; pressure sensors; and sensors for determining the quality of the core sample. In other examples, the sensors may include various types of imaging devices, including optical, acoustic electrical and/or x-ray tomographic devices. In examples wherein the telemetry transceiver 50 transmits signals over wired drill pipe, it may be possible to analyze images from one or more of the foregoing types of sensors as the formation sample is being created by the bit 12 essentially in real time during the drilling of the wellbore. Such analysis may assist the wellbore operator in deciding future activities with respect to drilling and/or completing the wellbore.

It will be readily appreciated by those skilled in the art that during drilling of the wellbore (18 in FIG. 1), the shape of the wellbore and the resulting actual rotational motion of the drill bit (12 in FIG. 1) will depend to some extent on the type of formation being drilled. For certain types of formations not usually associated with hydrocarbon bearing reservoirs, e.g., "shale", it may be unnecessary or undesirable to extract samples through the drill bit, but rather to drill such formations as rapidly as possible. In such circumstances, the drill string (20 in FIG. 1) may be operated using parameters that result in erratic (other than uniaxial) rotation. Such rotation may in fact preclude efficient creation of rock samples and their movement through the orifice (10F in FIG. 1). In one example of a method according to the invention, when the sensors on the MWD instrument (16 in FIG. 1) are indicative of a subsurface formation in which samples are highly desired, the drilling rig operator may adjust the operating parameters (axial force on the bit and rotation rate) so as to stabilize the rotation along the bit axis and increase the probability of obtaining well defined formation samples.

A possible advantage of using a separate housing and bit body as shown in FIG. 2 for a sample taking and analysis device is that the bit may be readily replaced when it becomes worn, without the need to remove the active components for making measurements of the sample that are disposed in the housing 10A. It should be clearly understood that it is also possible to include all the components shown disposed in the housing 10A in a unitary bit body having suitable spaces therein for the illustrated components. Thus, for purposes of defining the scope of the invention, the passageway may be considered as extending through a single housing or bit body, or through a combination bit body and separate housing as shown herein.

A wellbore formation sample acquisition and analysis device as explained herein may improve the quality of evaluation of subsurface reservoirs, while reducing the time needed to analyze physical samples of formation.

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.

1. A wellbore formation sample acquisition and analysis instrument, comprising:
   an annular drill bit configured to couple to one end of a drill string, the bit defining a passageway extending from a cutting face thereof to an exterior surface at a longitudinally spaced apart position from the cutting face; and
   at least one sensor configured to measure a selected parameter of a sample of subsurface formation urged into the passageway by action of the cutting face against subsurface formations, whereby samples of the subsurface formations are ejected from the exterior surface end of the passageway by the samples entering the cutting face end thereof and further wherein an internal diameter of the passageway increases from the cutting face to the exterior surface.

2. (canceled)

3. The instrument of claim 1 wherein at least one sensor comprises at least one of electrical resistivity sensors, acoustic velocity sensor, density sensor, neutron porosity sensor, neutron capture cross section sensor, natural gamma radiation sensor, neutron activated gamma radiation sensor, imaging sensor and nuclear magnetic resonance relaxometry sensor.
4. The instrument of claim 1 wherein the at least one sensor is disposed in a housing releasably coupled to a bit body, the bit body having cutting elements thereon.

5. The instrument of claim 4, wherein the housing comprises a communications couple configured to communicate with a wired drill pipe system.

6. The instrument of claim 1 further comprising a telemetry transmitter configured to transmit signals representative of measurements made by the at least one sensor directly or indirectly to the Earth’s surface.

7. The instrument of claim 6, wherein the telemetry transmitter comprises a wired drill pipe transmitter.

8. The instrument of claim 6, wherein the telemetry transmitter comprises a mud pulse telemetry.

9. A method for analyzing subsurface formations, comprising:
drilling samples of the subsurface formations while drilling a wellbore through the sub surface formations;
analyzing the samples by moving the samples proximate at least one sensor associated with a drill string used to drill the wellbore;
transmitting a measurement related to the samples in substantially real-time to a remote location through at least a portion of the drill string wherein a portion of the drill string comprises wired drill pipe; and
discharging the analyzed samples into an annular space between the drill string and a wall of the wellbore.

10. The method of claim 9 wherein the at least one sensor comprises at least one of electrical resistivity sensors, acoustic velocity sensor, density sensor, neutron porosity sensor, neutron capture cross section sensor, natural gamma radiation sensor, neutron activated gamma radiation sensor, imaging sensor and nuclear magnetic resonance relaxometry sensor.

11. The method of claim 9 wherein the remote location is the Earth’s surface.

12. The method of claim 11, wherein communicating signals from the at least sensor to the Earth’s surface comprises transmitting the signals from the at least one sensor via a wired drill pipe.

13. The method of claim 11, wherein communicating signals from the at least sensor to the Earth’s surface comprises transmitting the signals from the at least one sensor via mud pulse telemetry.

14. A wellbore formation sample acquisition and analysis instrument, comprising:
means for drilling a wellbore;
means for collecting a formation sample;
means for analyzing the formation sample;
means for transmitting data substantially in real-time related to the analysis of the formation sample to the surface through at least a portion of a drill string; and
means for ejecting the formation sample.

15. The wellbore formation sample acquisition and analysis instrument of claim 14 wherein at least a portion of the drill string comprises wired drill pipe.

16. The wellbore formation sample acquisition and analysis instrument of claim 15 further comprising a continuous passageway extending through a single housing from an annular drill bit to the means for ejecting the formation sample.

17. The wellbore formation sample acquisition and analysis instrument of claim 16 wherein the continuous passageway gradually expands in internal diameter from the annular drill bit to the means for ejecting the formation sample.

18. The wellbore formation sample acquisition and analysis instrument of claim 14 wherein the means for analyzing the formation sample includes a imaging device.

19. The wellbore formation sample acquisition and analysis instrument of claim 9 further comprising transmitting an image of the samples through the portion of the drill string comprising wired drill pipe.

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