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(54) Title: DETERMINING PHYSICAL PROPERTIES OF SOLID MATERIALS SUSPENDED IN A DRILLING FLUID

(57) Abstract: Determining physical properties of samples suspended in a drilling fluid automatic method for determining physical properties of solid materials (S), such as drill cuttings, suspended in a drilling fluid (F) while drilling a borehole (6) for extraction of a natural resource, in particular oil or gas, contained in a subterranean reservoir, comprising the steps of - extracting the drilling fluid (F) suspending samples (S) originating from a drilling depth (D) of the borehole (6); - separating the samples (S) from the drilling fluid (F); - analysing the separated samples (S) by means of electron microscopy, X-ray spectroscopy, magnetic resonance imaging and/or computer tomography, the step of analysing including the generation of at least one image of at least one of the samples (S) and the determination of at least one physical property of the at least one sample (S); - repeating the steps of extracting, separating and analysing for different samples originating from different drilling depths (D).
DETERMINING PHYSICAL PROPERTIES OF SOLID MATERIALS SUSPENDED IN A DRILLING FLUID

The invention generally refers to the field of mining and exploration. More particularly, the invention relates to an automated method and an apparatus for determining physical properties of samples suspended in a drilling fluid, wherein the physical properties of the samples are determined while a borehole for extraction of a natural resource, particular oil or gas, contained in a subterranean reservoir is drilled.

Borehole or well drilling is the process of drilling a hole in the ground for either the extraction of a natural resource such as water, gas or oil or for the exploration of a nature, in particular in search of metallic ores. A concept known by the term "Measurement While Drilling" (MWD) describes methods and devices developed to perform drilling related measurements downhole and transmit information to the surface while drilling a borehole. The acquired data is used for reservoir development strategy and operational decisions in the field.

However, the data acquired by MWD processes according to prior art lack the precision necessary for a comprehensive reservoir development planning. Hence, additional and expensive procedures of well logging are usually applied that are capable of estimating detailed reservoir properties such as the porosity, permeability or lithology of various subterranean rock formations.

Detailed records, i.e. well logs, of the geologic formations penetrated by boreholes are typically based either on visual inspection of samples brought to the surface (geological logs) or on physical measurements performed by instruments lowered into the borehole or well (geophysical logs). Well logging is practised nowadays during all phases of the devel-
Development of an extraction site, i.e. during drilling, completing, producing and abandoning of the borehole or the well.

The operator of the extraction site usually has to stop the production of the borehole or well when well logging procedures are performed. Hence, the development of alternative procedures that may avoid a delay of production are desired.

Existing MWD devices are capable of performing various measurements such as measuring naturally occurring gamma radiation to characterise the rock or sediment in the borehole. Furthermore, MWD device are capable of measuring borehole pressure, temperature, vibration, torque and the like. Advanced MWD devices of the prior art are adapted to measure formation pressure and take information samples. MWD devices additional provide means of communication for operating rotary steering tools.

Furthermore, MWD devices may be provided with means of digital storage so that measurement results may be digitally stored. Additionally, measurements results may be transmitted digitally to the surface via mud pulse telemetry. Mud pulse telemetry describes a method of data transmission, wherein pressure fluctuations are generated in the drilling fluid and used as signals. A downhole valve may be operated to restrict the flow of the drilling fluid or slurry according to the digital information to be transmitted. Accordingly, pressure fluctuations propagating within the drilling fluid are received by pressure sensors. The pressure fluctuations may also be used as signals for controlling the MWD device.

In particular in the field of petroleum industry, special core analysis provides supplementary information on the subterranean rock formations abundant at the extraction site. Special core analysis includes laboratory experiments performed on core plugs or core samples taken from the natural reservoir. As a result, core analysis requires expensive procedures for acquisition of the core samples.
Additionally, procedures of mud logging and sample logging are well established in the state of art. A standard mud log usually includes real-time drilling parameters such as a rate of penetration, lithology, flow line temperature, mud weight and/or estimated pore pressure. Chemical parameters may include the determination of concentration's of hydrocarbons and/or chlorides. Sample logs are usually made by examining samples or cuttings circulated to the surface by the drilling fluid, sometimes also called drilling mud, in rotary drilling. The samples are suspended in the drilling fluid that enters the borehole via a drill pipe, sometimes also called drill sting. Accordingly, samples originating from a drilling depth return to the surface via an annulus of the borehole. The samples are then transported to separation devices, in particular shale shakers, for separation from the drilling fluid. Shale shakers typically comprise flat sheets of wire mesh screens or sheets that shake or vibrate so as to separate the samples from the fluid as drilling mud flows through them. Samples are collected at regular time intervals and analysed and described by a geologist or a mud logger. Although sand and shale make up the majority of the samples encountered while drilling boreholes, depending on the location, any number of formations can actually be encountered.

It is an object of the present invention to provide an automated method for determining physical properties of the samples suspended in the drilling fluid that is capable of providing a comprehensive survey of the extraction site while minimising production delay.

According to the invention, the object is achieved by an automated method for determining physical properties of samples suspended in a drilling fluid while drilling a borehole for extraction of a natural resource, in particular oil or gas, contained in a subterranean reservoir, that comprises the steps of
- extracting the drilling fluid suspending samples originating from a drilling depth from the borehole;
- separating the samples from the drilling fluid;
- analysing the separated samples by means of electron microscopy, magnetic resonance imaging and/or computer tomography, the step of analysing including the generation of at least one image of at least one of the samples and the determination of at least one physical property of the at least one sample;
- repeating the steps of extracting, separating and analysing for different samples originating from different drilling depths.

Hence, the application of the sophisticated possibilities provided by modern electron microscopy, magnetic resonance imaging and/or computer tomography for real time monitoring physical properties during the drilling procedure of the borehole is proposed. The drilling fluid suspending the samples originating from one of the drilling depths is automatically extracted from the borehole via the annulus and transported to a separation device. The samples are separated from the drilling fluid, in particular by means of sieving. The separated samples are then transported to an analysis device capable of analysing the separated samples by means of electron microscopy, magnetic resonance imaging and/or computer tomography. The samples are analysed in a manner such that at least one image of the at least one of the sample is generated and at least one physical property of the least one sample is automatically determined. The steps of extracting, separating and analysing is repeated for different drilling depths, i.e. different samples are automatically extracted, separated and analysed at regular time intervals during the drilling procedure of the borehole. The method for determining the physical properties of the samples may be fully automated so that the determination of the physical properties occurs in real time during the drilling procedure. Additionally, comprehensive information on the various rock formations may be collected by the sophisticated methods of electron microscopy, magnetic resonance imaging and/or computer tomography. A comprehensive survey including the data of determined physical properties of samples originating from different rock formation may be used as the basis for both
operational decisions while drilling and for reservoir development strategy.

Preferably, the at least one property is determined by means of image processing. Image processing is a means suitable for express analysis as algorithms are available that are capable of determining parameters relating to physical properties of the samples from image data in real time. Consequently, the procedure of drilling the borehole does not have to be interrupted for determination of the at least one physical property and production delay is minimised.

According to various embodiments of the invention, the at least one physical property is a size, porosity or crystal structure of the at least one sample or an average size, in particular average size of pores, of the samples originating from one of the rock formations of the subterranean reservoir. The at least one physical property is determined from the image data of the at least one image. In further development of the invention, it is proposed to generate a series of images of the at least one sample for various scales. The at least one physical property may be determined from the series of images with increased accuracy. The physical property is preferably automatically determined by the means of image processing, whereby the surface of the at least one sample is automatically recognised and evaluated by a suitable computerised method, in particular an image processing algorithm.

According to a preferred embodiment of the invention, the at least one image is generated from back-scattered electrons. Electron microscopy is a powerful technique to image the microstructure in particular of porous samples that has already found application in digital rock physics including thin-section imaging to build three dimensional porous media models using process-based geostatistical modelling, multiscale imaging for shale and carbonate analysis, nano-resolution three dimensional image reconstruction, sample mineral content and special distribution study, and qualita-
tive core structure analysis for engineering and research and development purposes.

Electron microscopy, computer tomography and/or magnetic resonance imaging is now suggested to be performed directly on the extraction site for analysing the contents of the drilling mud emerging from the annulus of the borehole during the process of drilling. In combination with high-performance image processing means, the method may be automated so as to provide key information about the various rock formations of the natural reservoir in minimal time. The drilling of additional boreholes for surveillance purposes only is thus obsolete. Furthermore, images generated from back-scattered electrons are provided with sufficient resolution so that the at least one physical property may be determined with improved accuracy.

The analysis of the samples originating from one of drilling depths is preferably supplemented by means of x-ray spectroscopy. Accordingly, the step of analysing includes analysing the at least one sample by means of x-ray spectroscopy and determining at least one additional physical property from data provided by the x-ray spectroscopy. Alternatively, a region of the at least one sample is analysed by means of x-ray spectroscopy. Recording of spectra provides additional information, in particular about chemical constituents included in the at least one sample.

It is preferred to analyse the at least one sample or a region of the at least one sample by means of energy dispersive x-ray spectroscopy. Energy-dispersive x-ray spectroscopy provides an analytical tool for the elemental and/or chemical characterisation of the at least one sample. It includes the step of focussing a beam of electrons or x-rays on the at least one sample or the region of the at least one sample so as to stimulate the emission of characteristic x-rays. The additional physical property is determined from the observed characteristic x-ray spectra.
Accordingly, the at least one additional physical property determined by means of x-ray spectroscopy is a concentration of chemical constituents included in the at least one sample. In particular, a concentration of a chemical element such as oxygen, sodium, magnesium, aluminium, silicon, chloride, potassium, calcium, titan, iron, carbon, phosphorus, and/or sulphur may be obtained. Furthermore, chemical compounds contained in the at least one sample are identified by analysing the data of concentrations of different chemical elements.

For example, the at least one sample may be identified as containing SiO₂ or quartz when the concentrations for silicon and oxygen substantially corresponds to a relation 1 : 2. The concentrations of chemical elements are determined by the observed intensities of the characteristic x-ray spectra.

In further development of the invention, it is proposed to automatically select the region of the at least one sample analysed by means of the x-ray spectroscopy by a means of image processing. Accordingly, the beam of x-rays is automatically focussed on a region that is of particular interest and includes a pre-determined structure that is recognised by image processing. Parameters used for the selection of the region may include a crystal structure, porosity, pore size or the like previously determined by said means of image processing. Accordingly, a fully automated method capable of determining various physical properties including chemical characteristics is provided.

In further development of the invention, it is proposed to continuously extract the drilling fluid suspending the samples from the borehole and to continuously separate the samples from the drilling fluid and to continuously analyse the samples while the borehole is drilled. Preferably, the physical properties of the samples originating from different drilling depths are determined in real time during the process of borehole drilling. Alternatively, the images characterising the samples and/or the spectra recorded by means of x-ray spectroscopy are stored in a suitable digital storage means for later analysis.
Alternative embodiments utilising three dimensional computer tomography or magnetic resonance imaging include, during the step of analysis, the rotation of the at least one sample or the rotation of a computer tomograph or a magnetic resonance tomograph so as to provide three dimensional image data suitable for generating three dimensional images of the at least one sample. During the separation step, the samples are cleaned thoroughly so that accurate images may be acquired by means of a three dimensional tomography.

Preferably, the physical properties and/or the additional physical properties of the samples originating from different drilling depths are recorded in a well log. Preferably, all physical properties and additional physical properties determined for each sample and for each drilling depth are recorded in the well log along with the values for the drilling depth or other drilling parameters. Hence, a comprehensive survey of the natural reservoir is generated. The well log provides information that may be used for operational decisions when drilling the borehole or for considerations on further development of the extraction site. It is suggested to preferably record physical properties and/or additional physical properties characterising various subterranean rock formations of the natural reservoir such as porosities, crystal structures, chemical constituents, concentration of existing chemical compounds, gamma ray emission and others with respect to the depth in which the corresponding rock formation may be found.

Furthermore, the invention relates to an apparatus for determining physical properties of samples suspended in the drilling fluid while drilling the borehole for extraction of a natural resource, in particular oil or gas, contained in the subterranean reservoir that is adapted to execute the method as described herein before. The apparatus comprises a first means of transport for transporting extracted drilling fluid suspending samples originating from a drilling depth of the borehole to a separation device, the separation device for
separating the samples from the drilling fluid, a second means of transport for transporting samples separated from the drilling fluid to an analysis device and the analysis device for analysing the separated samples by means of electron microscopy, magnetic resonance imaging or computer tomography. The analysis devices is adapted to generate at least one image of the samples and the determination of at least one physical property of the at least one sample. The first and second means of transport may be configured as suitable piping, conveyor belt or the like. In one preferred embodiment, the separation device is a shale shaker adapted to separate the samples from the drilling fluid by means of sieving or filtering. According to alternative embodiments of the invention, the analysis device comprises at least one of an electron microscope, magnetic resonance tomograph and/or computer tomograph. The apparatus allows for an analysis of samples collected at different drilling depths of the borehole. Moreover the analysis may be performed at the extraction site and in real time so as to supply the operator drilling the borehole with information allowing for, in particular, adoption of at least one drilling parameter to the at least one determined physical property. Drilling parameters include, amongst others, a rate of penetration and/or a torque exerted on the drill bit.

Preferably, the analysis device is capable of image processing. The analysis device thus includes suitable analysis electronics such as computers running suitable algorithms and/or software, in particular software capable of imaging processing.

Furthermore, it is preferred that the analysis device comprises an electron spectrometer, in particular an energy dispersive electron spectrometer, so that spectra of samples may be determined. Determination of energy spectra by means of recording characteristic x-rays emitted from the samples allows for evaluation of chemical constituents, in particular concentrations of chemical elements existing in the samples. Accordingly, the additional physical property determined by
means of x-ray spectroscopy may provide key information for
the exploration of the natural resource.

In further development of the invention, the apparatus is ca-
5 pable of continuously extracting the samples from the bore-
hole, continuously separating the samples from the drilling
fluid and continuously analysing the samples. Accordingly,
the well log is automatically recorded during the drilling
process of the borehole.

In the following, the invention is described in a more detail
10 with reference to exemplary embodiments and with reference to
figures, wherein

15 fig. 1. schematically illustrates an apparatus for deter-
mining physical properties of samples extracted
from subterranean rock formations;

fig. 2. an image of the extracted sample that was recorded
by means of electron microscopy;

fig. 3. the sample of fig. 2 with porous and a solid phases
indicated;

25 fig. 4. another image generated by means of electron mi-
croscopy, wherein a selected region is further ana-
lysed by means of x-ray spectroscopy; and

fig. 5. an exemplary spectrum recorded by means of x-ray
spectroscopy.

Fig. 1 schematically illustrates an apparatus 1 capable of
determining physical properties of samples S contained in
subterranean rock formations 2 located at an extraction site
3 of a natural reservoir. The apparatus 1 comprises a first
means of transport 4 configured as a pipe adapted to collect
drilling fluid F suspending samples S from an annulus 5 of
the borehole 6. The drilling fluid F suspending the samples S
originating from a drilling depth D of the borehole 6 is
transported to a separation device 7 arranged as a shale shaker. The separation device 7 comprises an arrangement of wire grids, sieves or the like suitable for extracting samples S of suitable size from the drilling fluid F. A second means of transport 8 configured as a conveyor belt transports the separated samples S to an analysis device 9 that includes an electron microscope capable of generating multi-scale images of the samples S.

In an alternative embodiment of the invention, the analysis device 9 comprises a computer tomograph. In another alternative embodiment, the analysis device 9 is provided with a magnetic resonance tomograph.

Additionally, the analysis device 9 comprises an x-ray spectrometer capable of analysing the samples S by irradiating regions of the samples S with a focussed x-ray beam. Characteristic x-rays emitting from the irradiated regions of the samples are recorded as spectra containing information about chemical constituents.

The drilling fluid F carries the samples S excavated by a drill bit (not illustrated) up to the surface. The drilling fluid F is thixotropic and becomes a gel under static conditions. This keeps the cuttings or samples S suspended when a drilling process is interrupted, for example for maintenance purposes.

During drilling of the borehole 6 a drill string 10 carrying the drill bit is lowered by a rate of penetration. The drilling fluid F enters the borehole 6 via the drill string 10 and carries samples S from the bottom of the borehole 6 located at depth D back to the surface. The annulus 5 defined as the space between the boundaries of the borehole 6 and the drill string 10 conducts the drilling fluid F suspending the samples S up to the surface.

During drilling of the borehole 6, the drilling fluid F containing samples S is transported to the separation device 7.
After separation of the samples $S$, the drilling fluid $F$ is reintroduced into the drill string 10, whereas the separated samples $S$ are transported by the second means of transport 8 to the analysis device 9 for direct investigation at the extraction site 3.

As time progresses, different samples $S$ that originate from rock formations 2 of various drilling depths $D$ are collected and analysed by the analysis device 9.

At least one image of each of the collected samples $S$ is generated. The images are generated by means of electron microscopy, computer tomography or magnetic resonance imaging. Additionally, a selected region of each of the samples $S$ is investigated by means of x-ray spectroscopy.

Fig. 2 shows an exemplary image generated by means of electron microscopy of one of the samples $S$ as collected at different drilling depths $D$. Tomography and microstructure of the collected sample $S$ is analysed by using secondary and back-scattered electron regimes. The composition of the samples is investigated by means of energy dispersive x-ray spectroscopy. The image of fig. 2 illustrates schematically surfaces of the samples $S$.

Images of the samples $S$ are acquired using back scattered electrons regime with Z-contrast. For this regime, the gray scale level of a pixel depends on the composition: the higher the atomic number of an element located on the surface region being scanned, the brighter the pixel. The images recorded at different drilling depths $D$ are analysed by means of digital image processing.

As illustrated in fig. 3, the sample $S$ contains a solid phase $S_1$ and a porous phase $S_2$. The solid and porous phases $S_1$, $S_2$ were determined by means of image processing. Surface porosity was found to be 13.7 %.
Fig. 4 shows another image of another exemplary sample S extracted from the borehole 6. A region R selected by means of image processing is investigated by means of x-ray spectroscopy. In particular, the region R is investigated by means of energy-dispersive x-ray spectroscopy. The region R is irradiated with a high-energy beam of x-rays so as to excite electrons bound to the nuclei from a ground state into an excited state. When the excited electrons return to the ground state, characteristic x-rays are emitted. The chemical constituents, in particular chemical elements, are identified by observing the spectra of the characteristic x-rays. Furthermore, concentrations of chemical constituents are evaluated from relative intensities of characteristic peaks observed in the x-ray spectra.

For the exemplary region R shown in fig. 4, the following results (in atomic percent) were found:

<table>
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<tr>
<th></th>
<th>O</th>
<th>Na</th>
<th>Mg</th>
<th>Al</th>
<th>Si</th>
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<td>17,85</td>
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<td>-</td>
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<td>4,01</td>
<td>49,37</td>
<td>-</td>
<td>0,3</td>
<td>27,92</td>
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The determination of chemical compounds contained in the region R may be complicated as all phases may not be specified from x-ray spectroscopy alone. In particular x-ray spectroscopy does not allow for a detection of hydrogen and thus does not disambiguate between oxides and hydroxides. If such an identification is desired, it is suggested to supplement the measurement results by means of x-ray powder defraction analysis.

However, various mineral phases and chemical constituents of the samples S can be determined with x-ray spectroscopy. In particular the relative concentrations of different chemical elements identified in the samples S may be used. For example, a relation of the concentration of silicon and oxygen roughly being equal to 1 : 2 indicates that quartz (SiO₂) is contained in the sample X under investigation. Similarly, other phases like pyrites, silicates and others may be identified.
Fig. 5 shows an exemplary spectrum recorded by means of x-ray spectroscopy. The spectrum originates from a barium and boron rich inclusion found in the sample S. The intensity I of the observed characteristic x-rays versus energy E is shown.

Furthermore, physical properties like crystal symmetry and/or morphology are directly identified by means of image processing from the generated images. The physical properties of the samples S extracted from the borehole 6 at different time intervals correspond to different rock formations 2 located below the surface at various drilling depths D. All determined physical properties are recorded in well or electron microscopy log. In particular, the recorded log includes a plurality of graphs that show the acquired sample properties with respect to the drilling depth D. The EM-log (electron microscopy log) is a new type of well log that contains comprehensive information about the rock formations 2 of the extraction site 3. This reduces the necessity to acquire additional information by means of well logging subsequent to the drilling process as most of the reservoir properties are already included in the EM-logs.

In alternative embodiments, the at least one image of the at least one sample S collected at one of the drilling depths D is recorded by means of computer tomography or magnetic resonance imaging. Accordingly, the determined physical properties of the different samples S collected at different drilling depths D are recorded in a well log called computer tomography log (CT-log) or magnetic resonance imaging log (MRI-log). Essentially the CT-log and the MRI-log contain the information of the EM-log and is recorded in a similar way. Main difference of utilising means of computer tomography or magnetic resonance imaging is that the sample S is rotating during generation of the at least one image so as to create three dimensional images data. Alternatively, the computer tomograph or the magnetic resonance tomograph is rotated around the sample S when the image is recorded.
Direct proportionality of the sample S acquisition time and drilling depth D allows for generating graphs and logs similar to those produced by well logging procedures. However, the EM-, CT-, or MRI-log contains more comprehensive data and are already recorded during the drilling procedure so as to avoid unnecessary delays.

In particular, it is understood that the determined physical properties, such as concentrations of chemical compounds and/or elements are given by way of example only. A wide range of physical and/or chemical properties may be derived without having the scope of the invention.

Although the present invention has been described in detail with reference to the preferred embodiment, the present invention is not limited by the disclosed examples from which the skilled person is able to derive other variations without departing from the scope of the invention.
1. Automated method for determining physical properties of samples \((S)\) suspended in a drilling fluid \((F)\) while drilling a borehole for extraction of a natural resource, in particular oil or gas, contained in a subterranean reservoir, comprising the steps of:
   - extracting the drilling fluid \((F)\) suspending samples \((S)\) originating from a drilling depth \((D)\) of the borehole \((6)\);
   - separating the samples \((S)\) from the drilling fluid \((F)\);
   - analysing the separated samples \((S)\) by means of electron microscopy, magnetic resonance imaging and/or computer tomography, the step of analysing including the generation of at least one image of at least one of the samples \((S)\) and the determination of at least one physical property of the at least one sample \((S)\);
   - repeating the steps of extracting, separating and analysing for different samples originating from different drilling depths \((D)\).

2. Automated method according to claim 1, wherein the at least one property is determined by means of image processing.

3. Automated method according to claim 1 or 2, wherein the at least one physical property is a size, porosity or crystal structure of the at least one sample \((S)\) or an average size, in particular average size of pores, of the samples \((S)\).

4. Automated method according to one of the previous claims, wherein the at least one image is generated from back-scattered electrons.

5. Automated method according to one of the previous claims, wherein the step of analysing includes analysing the at least one sample \((S)\) or a region of the at least one sample \((S)\) by means of x-ray spectroscopy and determining at least one additional physical property from data provided by
the x-ray spectroscopy.

6. Automated method according to claim 5, wherein the at least one sample (S) or region (R) of the at least one sample (S) is analysed by means of energy dispersive x-ray spectroscopy.

7. Automated method according to claim 5 or 6, wherein the at least one additional physical property is a concentration of a chemical constituent, in particular a concentration of a chemical element, contained in the sample.

8. Automated method according to any of the claims 5 to 7, wherein the region (R) of the at least one sample analysed by the means of x-ray spectroscopy is automatically selected by means of image processing.

9. Automated method according to one of the previous claims, wherein the drilling fluid (F) suspending the samples (S) is continuously extracted from the borehole and the samples (S) are continuously separated from the drilling fluid (F) and continuously analysed while the borehole (6) is drilled.

10. Automated method according to one of the previous claims, wherein the physical properties and/or the additional physical properties of samples originating from different drilling depths (D) are recorded in a well log.

11. Apparatus (1) for determining physical properties of samples (S) suspended in a drilling fluid (F) while drilling a borehole (6) for extraction of a natural resource, in particular oil or gas, contained in a subterranean reservoir, the apparatus (1) being adapted to execute the method according to any of the previous claims, comprising
- a first means of transport (4) for transporting extracted drilling fluid (F) suspending samples (S) originating from a drilling depth (D) of the borehole (6) to a separation device (7)
- the separation device (7) for separating the samples (S) from the drilling fluid (F);
- a second means of transport (8) for transporting samples (S) separated from the drilling fluid (F) to an analysis device (9);
- the analysis device (9) for analysing the separated samples (S) by means of electron microscopy, magnetic resonance imaging or computer tomography, wherein the analysis device (9) is adapted to generate at least one image of at least one of the samples (S) and the determination of at least one physical property of the at least one sample (S).

12. Apparatus according to claim 11, wherein the analysis device (9) is capable of image processing.

13. Apparatus according to claim 11 or 12, wherein the analysis device (9) comprises an electron spectrometer, in particular an energy dispersive electron spectrometer.

14. Apparatus according to any of the previous claims 9 to 13, wherein the apparatus (9) is capable of continuously extracting the samples (S) from the borehole (6), continuously separating the samples (S) from the drilling fluid (F) and continuously analysing the samples (S).
FIG 4
### INTERNATIONAL SEARCH REPORT

**PCT/RU2012/000320**

**A. CLASSIFICATION OF SUBJECT MATTER**

**INV.** G01N33/28  E21B49/08

ADD.

According to International Patent Classification (IPC) onto both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

G01N  E21B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
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<td>X</td>
<td>US 6 386 026 B1 (ZAMFES KONSTANDINOS S [CA]) 14 May 2002 (2002-05-14) col umn 1, lines 5-10 col umn 3, line 54 - col umn 4, line 9 col umn 5, lines 38-51 figures 1,2,4 ----- /- - 1-14</td>
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X Further documents are listed in the continuation of Box C.  

X See patent family annex.

* Special categories of cited documents:

- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier application or patent but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed

**Date of the actual completion of the international search**

4 February 2013

**Date of mailing of the international search report**

08/02/2013

Name and mailing address of the ISA

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Fax: (+31-70) 340-3016

Authorized officer

Couteau, Olivier

Form PCT/ISA/210 (second sheet) (April 2005)
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<td>A</td>
<td>Wolf ET AL: &quot; Determination of the cleat angles during cutting of the RECOPOL coal seams, using CT-scans and image analysis on drilling cuttings and coal blocks&quot;, INTERNATIONAL JOURNAL OF COAL GEOLOGY, ELSEVIER, AMSTERDAM, NL, vol. 73, no. 3-4, 10 January 2008 (2008-01-10), pages 259-272, XP022415047, ISSN: 0166-5162, DOI: 10.1016/J.COAL.2007.06.001 abstract Sections 3 and 4 figures 5, 6</td>
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<td>wo 2010/000055 AI (CANADIAN LOGGING SYSTEMS CORP [CA]); ZAMFES KONSTANTINOS S [CA]) 7 January 2010 (2010-01-07) the whole document</td>
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