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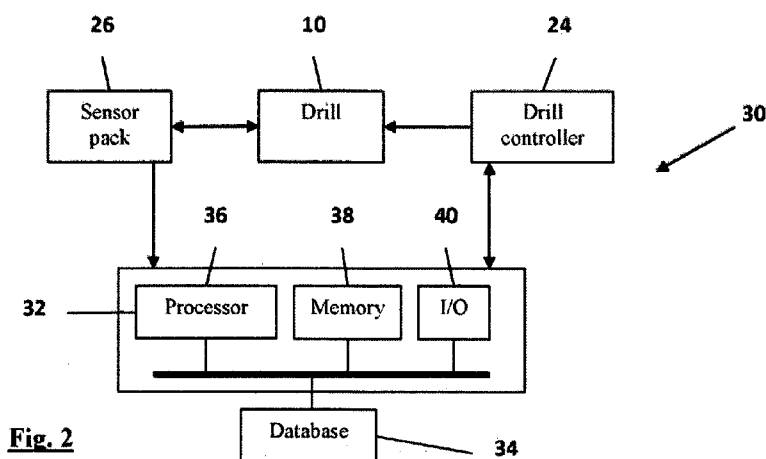
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(54) Title: A METHOD OF, AND A SYSTEM FOR, DRILLING TO A POSITION RELATIVE TO A GEOLOGICAL BOUNDARY



(57) **Abstract:** A system (30) for drilling to a position relative to a geological boundary in a geological formation includes a sensor pack (26) for sensing parameters associated with a drilling operation carried out in the geological formation by a drill (10). A data storage module (34) stores a geological model of the geological formation and data relating to the sensed parameters, the geological model including data relating to the geological boundary. A processor module (32) is configured to monitor the drilling operation using the data related to the sensed parameters and to locate the position of a drill bit of the drill (10) in the geological formation and its corresponding position within the geological model. The processor module (32) is further configured to generate an end point at a defined position relative to the geological boundary. A drill controller (24) communicates with the processor module (32), the drill controller (24) being configured to control operation of the drill 10 and to cause the drill (10) to cease drilling when the end point has been reached.

1.

**"A method of, and a system for, drilling to a position relative to a geological boundary"****Cross-Reference to Related Applications**

[1] The present application claims priority from Australian Provisional Patent Application No 2012902919 filed on 6 July 2012, the contents of which are incorporated in this specification by reference in their entirety.

**Technical Field**

[2] This disclosure relates, generally, to drilling technology and, more particularly, to a method of, and a system for, drilling to a position relative to a geological boundary.

**Background**

[3] At present, when mining metals or minerals that occur in stratigraphic bands such as, for example, coal, diamonds or copper, boreholes are drilled to a defined depth into stratigraphy using an operator-controlled drill to enable a waste blast to be performed to remove the overburden. If, for example, in an open-cut mine it is required to drill holes to the stratigraphic boundary separating overburden from a seam of material to be mined, the operator typically drills a certain number of boreholes into the seam and detects penetration of the seam by the colour of material deposited at a collar generated about an entrance to the borehole during the drilling operation.

[4] Standard procedure is to drill every fifth borehole into the seam and use the information gathered about the depth of the seam to inhibit penetration of the remaining boreholes into the seam to minimise the amount of seam material being removed with the overburden when subsequent blasting occurs. However, in practice it is common for all boreholes to be drilled into the seam. This results in a great deal of valuable seam material being lost when subsequent blasting occurs and the penetrated seam material is removed together with the overburden.

## Summary

- [5] In a first aspect, there is provided a method of drilling to a position relative to a geological boundary in a geological formation, the method including
- sensing borehole parameters while a borehole is being drilled in the geological formation;
  - feeding the sensed parameters to a controller which controls operation of a drill drilling the borehole;
  - using the sensed parameters to locate the position of a drill bit of the drill in the geological formation and its corresponding position within a geological model of the geological formation being drilled;
  - using the sensed parameters and the geological model also to locate the position of the drill bit of the drill relative to the geological boundary; and
  - selecting an end point at a defined position relative to the boundary and using the controller to drill to the end point.
- [6] The method may include selecting the end point by
- detecting a stratigraphic band arranged above the geological boundary; and
  - selecting a location relative to the stratigraphic band as the end point.
- [7] The method may include updating the geological model using the parameters sensed during drilling. In an embodiment, the method may include updating the geological model during drilling of a current borehole to the end point relative to the geological boundary for a subsequent borehole to be drilled.
- [8] The method may include sensing the borehole parameters using measurement-while-drilling (MWD) data. The method may include selecting the parameters from the group consisting of: weight on drill bit, rate of penetration, rotation rate, bit torque, temperature, depth, XYZ translation, gas pressure, spectral scan data, and combinations of the foregoing. Further, the method may include updating the geological model in real time during the drilling operation using the MWD data.
- [9] In an embodiment, the controller may be an autonomous controller and the method may include selecting the end point to be the geological boundary. In another embodiment,

the controller may be controlled by an operator and the method may include alerting the operator when the end point is reached so that the operator can control the drill to avoid or minimise penetration of the geological boundary.

[10] In a second aspect there is provided a method of drilling to a position relative to a geological boundary in a geological formation, the method including

- sensing borehole parameters while a borehole is being drilled in the geological formation;

- using a geological model of the geological formation including the geological boundary to determine an end point at a defined position relative to the boundary

- feeding the sensed parameters and the end point to a controller which controls operation of a drill drilling the borehole;

- using the controller to drill to the end point; and

- updating the geological model using the sensed parameters and updating the end point for a subsequent hole to be drilled.

[11] In a third aspect, there is provided a system for drilling to a position relative to a geological boundary in a geological formation, the system including

- a sensor pack for sensing parameters associated with a drilling operation carried out in the geological formation by a drill;

- a data storage module for storing a geological model of the geological formation and data relating to the sensed parameters, the geological model including data relating to the geological boundary;

- a processor module configured to monitor the drilling operation using the data related to the sensed parameters and to locate the position of a drill bit of the drill in the geological formation and its corresponding position within the geological model, the processor module being further configured to generate an end point arranged at a defined position relative to the geological boundary; and

- a drill controller in communication with the processor module, the drill controller being configured to control operation of the drill and to cause the drill to cease drilling when the end point has been reached.

- [12] The system processor module may be configured to select the end point by detecting a stratigraphic band arranged above the geological boundary; and selecting a location relative to the stratigraphic band as the end point.
- [13] The processor module may be operable to update the geological model using the parameters sensed during drilling. In an embodiment, the processor module may update the geological model during drilling of a current borehole to estimate the end point relative to the geological boundary for a subsequent borehole to be drilled by the drill.
- [14] The sensor pack may use measurement-while-drilling (MWD) sensors. The sensor pack may comprise sensors selected from the group consisting of: weight on drill bit, rate of penetration, rotation rate, bit torque, temperature, depth, XYZ translation, gas pressure, spectral scan data, and combinations of the foregoing.
- [15] The processor module may be configured to update the geological model in real time on receipt of data from the sensor pack.
- [16] In an embodiment, the drill may be an autonomous drill and the drill controller may be operable under the action of the processor module to cease drilling when the end point has been reached. In another embodiment, the drill may be an operator-controlled drill and the controller may be responsive to commands from the operator to cease drilling when the end point has been reached.
- [17] In a fourth aspect, there is provided a system for drilling to a position relative to a geological boundary in a geological formation, the system including
- a sensor pack for sensing parameters associated with a drilling operation carried out in the geological formation by a drill;
  - a data storage module for storing a geological model of the geological formation including the geological boundary, the data storage module further storing an end point arranged at a defined position relative to the geological boundary;
  - a processor module configured to monitor the drilling operation;
  - a drill controller in communication with the processor module, the drill controller being configured to control operation of the drill and to cause the drill to cease drilling when the end point has been reached; and

the processor module further being configured to use the sensed parameters to update the end point for a subsequent hole to be drilled by the drill.

[18] The processor module may be configured to generate the end point which is then stored in the data module.

[19] The disclosure extends also to software that, when installed on a computer, causes the computer to perform any of the methods described above.

[20] In a fifth aspect, there is provided a drill which includes  
a drilling platform;  
a support structure mounted on the platform;  
a drilling mechanism displaceably supported by the support structure, the drilling mechanism terminating in a drill bit for drilling a borehole; and  
a drill controller carried on the drilling platform, the drill controller being operative to control operation of the drilling mechanism and the drill controller further being responsive to commands to cease drilling when the drill bit reaches an end point arranged at a defined position relative to a geological boundary.

[21] The drill may include a sensor pack for sensing parameters relating to a drilling operation.

### **Brief Description of Drawings**

[22] Embodiments of the disclosure are now described by way of example only with reference to the accompanying drawings in which:-

[23] Fig. 1 shows a schematic, perspective view of a drill to be controlled;

[24] Fig. 2 shows a block diagram of an embodiment of a system for drilling to a position relative to a geological boundary in a geological formation;

[25] Fig. 3 shows a block diagram of the operation of a processor module of Fig. 3;

- [26] Fig. 4 shows a flow chart of an embodiment of a method of drilling to a position relative to a geological boundary in a geological formation;
- [27] Fig. 5 shows an example of a graphical display of the system;
- [28] Fig. 6 shows a plot of exploration holes indicating different stratigraphic bands in the geological formation to be drilled;
- [29] Fig. 7 shows a schematic representation of the geology of a geological formation to be drilled indicating the varying nature of stratigraphic bands of the geological formation; and
- [30] Fig. 8 shows a schematic representation of a blast hole being drilled to an end point.

#### **Detailed Description of Exemplary Embodiments**

[31] In open cut mining, overburden needs to be removed to access the metals or minerals (the "materials of interest") to be mined. Particularly in the case where the material of interest occurs in the form of a seam, a problem arises when boreholes are drilled through the overburden in that the boreholes penetrate the seam. When the boreholes are subsequently charged with explosives and the explosives are detonated, that part of the seam which has been penetrated is removed together with the overburden.

[32] It will be appreciated that, with the increasing economic value of the materials of interest, for example, coal, even the removal of a small amount of material from the seam during a waste blast to remove overburden could result in substantially less revenue being generated for the mine.

[33] While the present disclosure is of benefit in numerous applications, for ease of explanation, the present disclosure will be described with reference to its application to open-cut coal mining. Those skilled in the art will, however, appreciate that the present disclosure could readily be applied to other mining applications and, in particular, where the material of interest occurs in seams. Thus, the present disclosure is also readily applicable, for example, to diamond mining, copper mining, etc. It will further be appreciated that the present disclosure could be applied in underground mining applications as well where it is necessary or desirable to drill to a seam of a material of interest.

[34] To aid in the description of the system and method of the disclosure, reference is initially made to Fig. 1 of the drawings in which reference numeral 10 generally designates a self-propelled drilling rig, or drill, 10. The drill 10 comprises a platform 12 supported on displacing elements, generally in the form of tracked members, or tracks, 14, 16. A cabin 18 is arranged on the platform 12 and may or may not be populated by an operator depending on the mode of operation of the drill 10. In the case of more recent, fully autonomous drills 10, the cabin 18 is omitted.

[35] A support structure in the form of a drill mast 20 projects upwardly from the platform 12. A drill string (not shown) is supported by the drill mast 20, the drill string terminating, at its operatively lower end, in a drill bit 22.

[36] The drill 10 includes a drill controller 24 which is used for driving the tracks 14, 16 to propel the drill 10 over terrain, such as a bench of an open cut, in which boreholes are to be drilled. The drill controller 24 also controls operation of the drill string supported by the drill mast 20 and includes drive mechanisms for rotationally driving the drill string and percussive members for operating the drill string in a hammer or percussive mode.

[37] The drill 10 includes a sensor pack 26. The sensor pack 26 comprises various sensors as will be described in greater detail below. In particular, the sensors of the sensor pack 26 are measurement-while-drilling (MWD) sensors. The sensor pack 26 also includes a position determining sensor such as, for example, a GPS sensor 28 for determining the location of the drill 10 and the borehole drilled by the drill 10.

[38] Referring now to Fig. 2 of the drawings, an embodiment of a system for drilling to a position relative to a geological boundary in a geological formation is illustrated and is designated generally by the reference numeral 30. The system 30 includes the drill controller 24 and the sensor pack 26 referenced above. The sensor pack 26 communicates with components of the drill 10 and, in particular, the drill string and drill bit 22 for monitoring a drilling operation carried out by the drill 10 under the control of the drill controller 24.

[39] A processor module 32 receives data from the sensor pack 26 and uses the sensor data to update a geological model 46 (Fig. 3) of the region being drilled and/or to generate the geological model 46 as will be described in greater detail below. The system 10 includes a

data storage module, or database, 34 in which data relating to the parameters sensed by the sensor pack 26 are stored and which is accessible by the processor module 32. The data are used by the processor module 32 to enable the geological model 46 to be generated or updated. A geological model 46 which has been previously generated is stored in the database 34.

[40] The processor module 32 includes a processor 36, associated memory 38 and input/output devices 40 communicating with each other and the database 34 via a bus 42. The processor module 32 may either be arranged on the drill 10 or remotely from the drill 10 depending on the mode of operation of the drill 10. In the latter case, the processor module 32 may be configured to operate the drill 10 in a remote control manner or to allow the drill 10 to operate autonomously.

[41] The memory 38 stores code for execution by the processor 36 to perform the method of the disclosure. The input/output devices 40 include a display device 42, such as display screen, for displaying a display 50 such as that shown in Fig. 5 of the drawings.

[42] The sensor pack 26 includes a plurality of individual sensors 26.1 - 26.n and also includes the position determining sensor 28. The sensors 26.1-26.n include a weight on bit sensor, a rate of penetration sensor (which may measure pull down rate on the drill string), a rotation rate, a drill bit torque sensor, a temperature sensor, a depth sensor, XYZ translation sensors, one or more gas pressure sensors and one or more geophysical sensors for conducting spectral analysis of core samples removed from the drill *in situ*. For this purpose, the sensor pack 26 includes spectral scanning sensors 44 (Fig. 1) mounted on the drill platform 12 to enable real time spectral analysis of a borehole sample, in the form of drill chips, removed from the drill string to be conducted. The spectral analysis may incorporate gamma ray detection, neutron detection, or the like either on the drill chips or down the hole on the drill string proximate the drill bit 28. The geophysical sensors may also detect in-ground parameters such as gamma radiation occurring in the borehole being drilled by the drill 10.

[43] As illustrated in Fig. 3 of the drawings, the processor 36 of the processor module 32 is configured to receive data from a plurality of the sensors 26.1-26.n of the sensor pack 26 to conduct a real time analysis of the stratigraphic layers being drilled by the drill bit 22 of the drill 10. In one embodiment, the processor 36 updates a previously provided geological

model 46 in real time. In another embodiment, the processor 36 uses sensor data from the sensor pack 26 to generate a model of the geological formation in real time as the drilling operation proceeds.

[44] International Patent Application No. PCT/AU2011/000116 dated 4 February 2011 in the name of The University of Sydney and entitled "Rock property measurements while drilling", discloses a method of, and a system for, characterising in-ground rock types from measurement-while-drilling data in a mining environment. The disclosure of the international patent application provides a useful basis for generating a geological model for a region of interest being drilled and the contents of the application are incorporated herein by reference in their entirety.

[45] Another useful disclosure for obtaining a geological model for the region of interest being drilled is International Patent Application No. PCT/AU2010/000522 dated 12 May 2010 in the name of The University of Sydney and entitled "A method and system for data analysis and synthesis", the contents of which are incorporated herein by reference in their entirety.

[46] Yet another useful disclosure for obtaining a geological model for the region of interest being drilled is International Patent Application No. PCT/AU2011/001342 dated 21 October 2011 in the name of The University of Sydney and entitled "Method for large scale, non-reverting and distributed spatial estimation", the contents of which are incorporated herein by reference in their entirety.

[47] Still a further useful disclosure for obtaining a geological model for the region of interest being drilled is International Patent Application No. PCT/AU2009/001668 dated 21 December 2009 in the name of The University of Sydney and entitled "A method and system of data modelling", the contents of which are incorporated herein by reference in their entirety.

[48] The geological models of any of the above international patent applications, suitably modified if necessary, can thus be used as the initial geological model for the present disclosure. It will, however, be appreciated that any other suitable geological model, if

available, could be employed as an initial geological model of the geological formation being, or to be, drilled.

[49] While the above international applications provide reasonable bases for models which enable boundaries between stratigraphic layers to be determined or inferred, the international applications do not or may not provide boundary data with sufficient accuracy to minimise penetration of a seam of the material of interest.

[50] For example, as shown in Fig. 7, stratigraphic layers 47 of a geological formation 49 may undulate significantly or there may be a fault (not shown) intersecting the layers 47 causing displacement of the layers 47 on opposite sides of the fault. Hence, the previously generated or inferred geological model 46 may not be a sufficiently accurate representation of the geological formation 49. By updating the model 46 using data generated from the sensor pack 26, the model 46 can be updated during the drilling operation to improve the accuracy of the model 46.

[51] A particular benefit of the disclosure is that the system 30 affords the benefit of updating the model 46 for a subsequent borehole (not shown) to be generated. Hence, when the data from the current borehole 51 being drilled are received, the processor module 32 is configured to analyse the sensor data from that borehole 51 (and previous boreholes if necessary) to compare the data with stored data relating to the geological model and to update the geological model 46 for the subsequent borehole to be drilled. In this way the accuracy of the subsequent borehole to be drilled is improved and there is a lower likelihood of penetrating the seam containing the material of interest.

[52] Hence, the processor 36 of the processor module 32 of the system 30 receives the relevant data from the sensors 26.1-26.n of the sensor pack 26, the data if necessary, including data from the position determining sensor 28. The processor 36 accesses the geological model 46 in the database 32 and updates the data contained in the geological model 46 using real time data obtained from the sensor pack 26. From this, an updated geological model 46 (Fig. 3) is provided and a geological model map 48, containing a desired end point to which to drill a borehole, is generated. The geological model map 48 is provided by the processor module 32 to the drill controller 24 to control operation of the drill 10.

[53] The geological model map 48 is displayed as a display 50 on the display screen 42 and is visible to an operator, whether situated remotely from the drill 10 or on the drill 10, or a person monitoring operations, in the case of an autonomous drill 10. The display 50 comprises a three-dimensional view 52 of a bench 54 being drilled by the drill 10 as well as a cross-sectional display 56. The cross-sectional display 56 of the map 48 shows an overburden layer 58 such as, for example, shale, separated from a seam 60 of coal to be mined by a boundary 62, the boundary 62 being the top of the coal seam 60 of interest. The display 50 further shows a plurality of boreholes 64 drilled or to be drilled to an end point which, in this embodiment, is at the boundary 62. Instead of the end point being at the boundary, the end point could, instead, be a predetermined stand-off distance 'd' (Fig. 8) above the boundary 62 as will be described in greater detail below.

[54] While the end point has been described as a physical location in the geological model map 48, it will be appreciated that the end point could be defined in other ways. For example, the end point could be established by the processor module 32 determining that a plurality of parameters sensed by relevant sensors of the sensor pack 26 have each reached a predetermined value, the values of those parameters together defining the end point.

[55] It will be appreciated that, instead of using the geological model provided by the above referenced international patent applications, data relating to the bench 54 could be sourced in other ways, for example, by pre-drilling a number of holes in the bench 54 to infer the stratigraphic layout of the bench 54.

[56] In the case of an autonomous drill 10, the drill controller 24 receives updated information, in real time, from the processor module 32 of the geological model 46 and the end point on the map 48. The position of the end point of that particular borehole 64 being drilled is defined as the boundary 62 which is the transition between the overburden 58 and the coal seam 60 or, instead, the end point is the predetermined stand-off distance 'd' from the boundary 62.

[57] In the case of a remotely controlled drill 10, the display screen 42 is monitored by an operator. The processor module 32 sends instructions to the drill controller 24 to terminate drilling at the end point. In this case, the end point is arranged to be above the boundary 62, for example, when a stratigraphic layer above the seam 60 is penetrated so that the operator is

able to control the drill 10 to ensure that the drill bit 22 does not penetrate the coal seam 60 or penetrates the coal seam 60 only to a minimal extent.

[58] The drill 10 could also be operated by an operator seated in the cab 18 of the drill 10. In that case, the operator, either by monitoring the display 50 on the display screen 42 mounted in the cab 18, or after receiving instructions from a remote site, operates the drill controller 24 to cause the drill controller 24 to stop drilling when the drill bit 22 reaches the end point. Once again, in this case, the end point may be upstream of the boundary 62 to enable the operator to control the drill 10 to ensure that the drill bit 22 does not penetrate the coal seam 60 at all or only to a minimal extent.

[59] In the two latter cases, i.e. the remotely controlled drill 10 or the operator controlled drill 10, the system 30 may be operable to select a sub-economic seam of the material of interest as a marker band defining the end point for each hole to be drilled. Fig. 6 of the drawings shows a plot of exploration holes previously drilled from which the geology of the geological formation has been inferred and from which the geological model 46 has been generated. Fig. 8 shows a schematic representation of a blast hole being drilled to an end point 63 arranged at a stand-off distance 'd' above the boundary 62 of the seam 60.

[60] The seam containing the material of interest to be extracted is shown at 60 corresponding to the seam 60 in Fig. 5 of the drawings. A stratigraphic layer defining a marker band 61 overlies, and is spaced vertically above, the seam 60, the layer being a sub-economic layer of coal (or other mineral of interest) or it may be a geological layer of a different geology to the seam 60 to be extracted.

[61] The processor module 32 is configured to identify the marker band 61. Various ways of identifying the marker band 61 may be employed. One method may include, for example, using a characteristic rock hardness measure of the marker band 61 at an expected depth. The rock hardness measure may, for example, use Adjusted Penetration Rate from the MWD data of the drill 10 as described in the 2012 IEEE International Conference Paper on Robotics and Automation entitled "Automatic Rock Recognition from Drilling Performance Data" by Zhou et al.

[62] The processor module 32 sets the end point 63 to which the hole 64 is to be drilled at a predetermined distance below the marker band 61 to define the stand-off distance 'd' from the end point 63 to the boundary 62 at the top of the seam 60. For example, this stand-off distance 'd' may be about 300 mm – 500 mm above the boundary 62. In this way, the operator controls the drill 10 to cease drilling at the end point 63 below the marker band 61. Drilling to a depth below the marker band 61 as defined by the end point 63, but terminating drilling at the stand-off distance 'd' above the seam 60 prevents or minimises penetration of the seam 60 allowing more economically beneficial extraction of the seam 60 to occur. The marker band 61 is selected to be a stratigraphic layer that is easily detectable and has relatively constant spacing from the boundary 62 of the seam 60.

[63] While the use of the marker band 61 as the stand-off datum line has been described with reference to its application in the case of an operator-controlled drill 10, whether remotely controlled or by an operator accommodated on the drill 10, it will be understood that this marker band 61 could also be used in the case of an autonomously operated drill if desired.

[64] In Fig. 4, reference numeral 70 generally designates a flow chart showing an embodiment of a method of drilling to a position relative to a geological boundary in a geological formation. At step 72 of the method, the drilling operation is initialised. Initialisation involves positioning of the drill 10 at the location where a borehole 64 is to be drilled in the bench 54. The initialisation procedure further involves lowering the drill bit 22 into abutment with the surface into which the borehole 64 is to be drilled. The drill bit 22 is lowered under the control of the drill controller 24.

[65] The drilling operation itself then commences at step 74 under control of the drill controller 24. While drilling proceeds, various parameters relating to the drilling operation are sent to the processor module 32 at step 76 using the sensor pack 26. As indicated above, the sensors 26.1-26.n monitor various parameters relating to the drilling operation.

[66] At step 78, the processor 36 determines whether or not a geological model for the bench 54 being drilled is already available. If not, the processor 36 of the processor module 32 generates the model using an algorithm as shown at step 80. The processor 36 of the processor module 32 uses MWD data from the sensor pack 26 in the algorithm to generate the

geological model 46 in real time. Data from the sensors 26.1-26.n are used in the algorithm to improve the accuracy of the geological model 46.

[67] If a model 46 already exists, the model 46 is updated at step 82 using the MWD data relating to the sensed parameters received from the sensor pack 26.

[68] The processor module 32 monitors the drilling progress as shown at step 84 and queries at step 86 whether or not the end point for that borehole 64 in the geological map 48 has been reached. As described above, in the case of an autonomous drill 10, the end point is selected by the processor module 32 to be the boundary 62 between the overburden 58 and the seam 60. If the drill 10 is being operated in a non-autonomous mode or, if desired, also when the drill 10 is operated in an autonomous mode, or if it is difficult to infer where the boundary 62 is from the data available in the geological model 46, the end point 63 may be selected by the processor module 32 to be at the stand-off distance 'd' above the boundary 62 so that the drill bit 22 stands off before intersecting the boundary 62. This also inhibits any overshoot of the drill bit 22 and, as a result, inhibits penetration of the seam 60 at all or only to a very minimal extent.

[69] If the processor module 32 determines that the end point has been reached, a command is sent by the processor module 32 to the drill controller 24 to stop drilling as shown at step 88.

[70] If the processor module 32 determines that the end point has not yet been reached, drilling continues, as described above, until the processor module 32 determines that the end point has been reached at which time the drill controller 24 is commanded to stop the drilling operation.

[71] It is to be noted that, in generating the geological model 46, the algorithm used may employ mathematical modelling on sample data derived from data relating to the bench 54. This mathematical modelling may include suitable interpolation techniques or other mathematical techniques such as Gaussian Processes.

[72] It is an advantage of the described embodiments of the disclosure that a method and system are provided which facilitate real time updating of an in-ground geological model to

assist in more accurately determining the boundary between overburden and material to be mined. Hence, the likelihood of drilling into the material to be mined and which results in subsequent removal of that material, is reduced. This results in increased recovery of mined material with the resultant improved economics associated with operating the mine.

[73] Any discussion of documents, acts, materials, devices, articles or the like which has been included in the present specification is not to be taken as an admission that any or all of these matters form part of the prior art base or were common general knowledge in the field relevant to the present disclosure as it existed before the priority date of each claim of this application.

[74] It will be appreciated by persons skilled in the art that numerous variations and/or modifications may be made to the above-described embodiments, without departing from the broad general scope of the present disclosure. The present embodiments are, therefore, to be considered in all respects as illustrative and not restrictive.

## CLAIMS:

1. A method of drilling to a position relative to a geological boundary in a geological formation, the method including
  - sensing borehole parameters while a borehole is being drilled in the geological formation;
  - feeding the sensed parameters to a controller which controls operation of a drill drilling the borehole;
  - using the sensed parameters to locate the position of a drill bit of the drill in the geological formation and its corresponding position within a geological model of the geological formation being drilled;
  - using the sensed parameters and the geological model also to locate the position of the drill bit of the drill relative to the geological boundary; and
  - selecting an end point at a defined position relative to the boundary and using the controller to drill to the end point.
2. The method of claim 1 which includes selecting the end point by
  - detecting a stratigraphic band arranged above the geological boundary; and
  - selecting a location relative to the stratigraphic band as the end point.
3. The method of claim 1 or claim 2 which includes updating the geological model using the parameters sensed during drilling.
4. The method of any one of the preceding claims which includes updating the geological model during drilling of a current borehole to the end point relative to the geological boundary for a subsequent borehole to be drilled.
5. The method of any one of the preceding claims which includes sensing the borehole parameters using measurement-while-drilling (MWD) data.
6. The method of claim 5 which includes selecting the parameters from the group consisting of: weight on drill bit, rate of penetration, rotation rate, bit torque, temperature, depth, XYZ translation, gas pressure, spectral scan data, and combinations of the foregoing.

7. The method of any one of the preceding claims which includes updating the geological model in real time during the drilling operation using the MWD data.
8. The method of any one of the preceding claims in which the controller is an autonomous controller and in which the method includes selecting the end point to be the geological boundary.
9. The method of any one of claims 1 to 7 in which the controller is controlled by an operator and in which the method includes alerting the operator when the end point is reached so that the operator can control the drill to avoid or minimise penetration of the geological boundary.
10. A method of drilling to a position relative to a geological boundary in a geological formation, the method including
  - sensing borehole parameters while a borehole is being drilled in the geological formation;
  - using a geological model of the geological formation including the geological boundary to determine an end point at a defined position relative to the boundary
  - feeding the sensed parameters and the end point to a controller which controls operation of a drill drilling the borehole;
  - using the controller to drill to the end point; and
  - updating the geological model using the sensed parameters and updating the end point for a subsequent hole to be drilled.
11. A system for drilling to a position relative to a geological boundary in a geological formation, the system including
  - a sensor pack for sensing parameters associated with a drilling operation carried out in the geological formation by a drill;
  - a data storage module for storing a geological model of the geological formation and data relating to the sensed parameters, the geological model including data relating to the geological boundary;
  - a processor module configured to monitor the drilling operation using the data related to the sensed parameters and to locate the position of a drill bit of the drill in the geological formation and its corresponding position within the geological model, the processor module

being further configured to generate an end point arranged at a defined position relative to the geological boundary; and

a drill controller in communication with the processor module, the drill controller being configured to control operation of the drill and to cause the drill to cease drilling when the end point has been reached.

12. The system of claim 11 in which the processor module is configured to select the end point by

detecting a stratigraphic band arranged above the geological boundary; and  
selecting a location relative to the stratigraphic band as the end point.

13. The system of claim 11 or claim 12 in which the processor module is operable to update the geological model using the parameters sensed during drilling.

14. The system of any one of claims 11 to 13 in which the processor module updates the geological model during drilling of a current borehole to estimate the end point relative to the geological boundary for a subsequent borehole to be drilled by the drill.

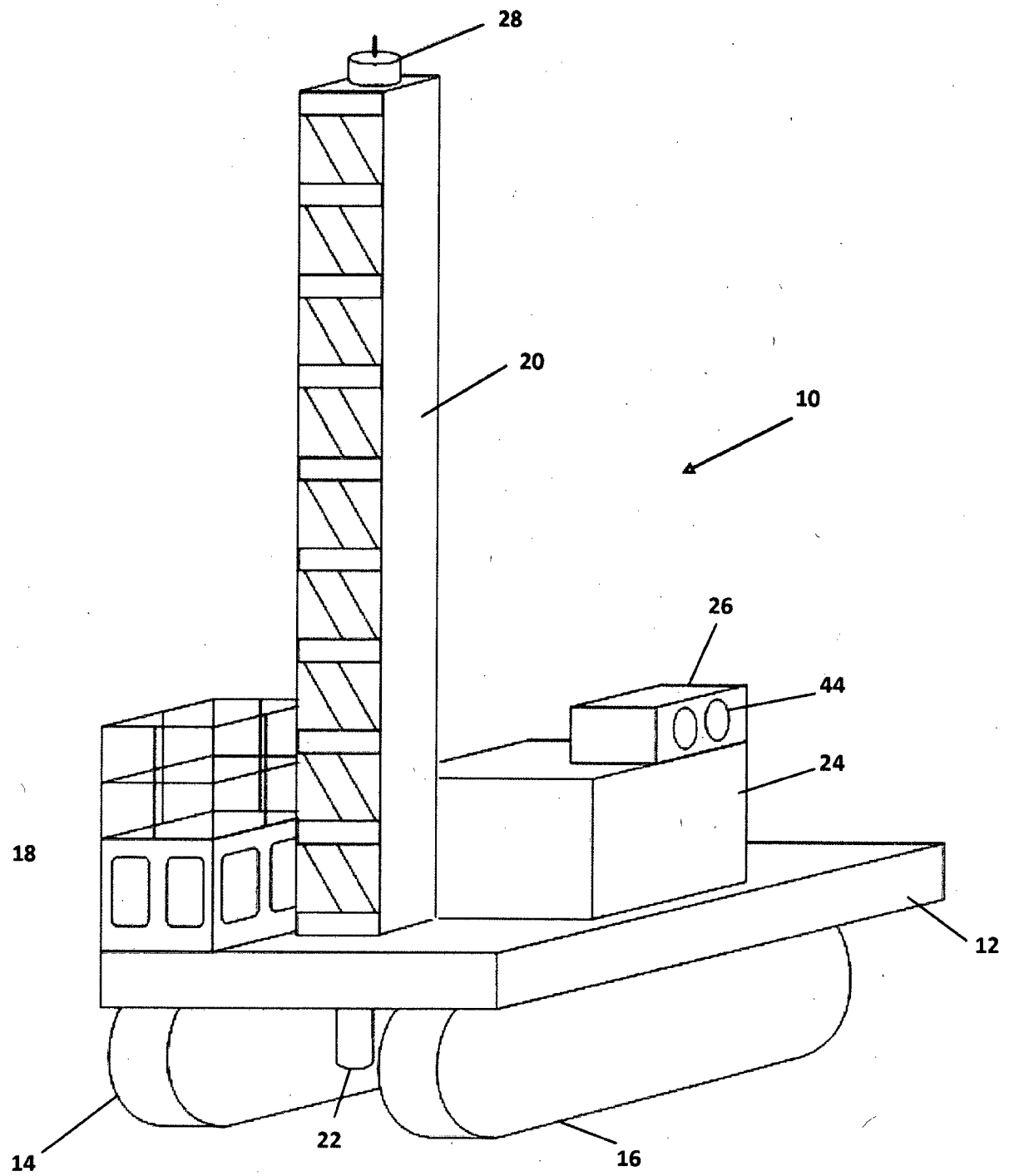
15. The system of any one of claims 11 to 14 in which the sensor pack uses measurement-while-drilling (MWD) sensors.

16. The system of claim 15 in which the sensor pack comprises sensors selected from the group consisting of: weight on drill bit, rate of penetration, rotation rate, bit torque, temperature, depth, XYZ translation, gas pressure, spectral scan data, and combinations of the foregoing.

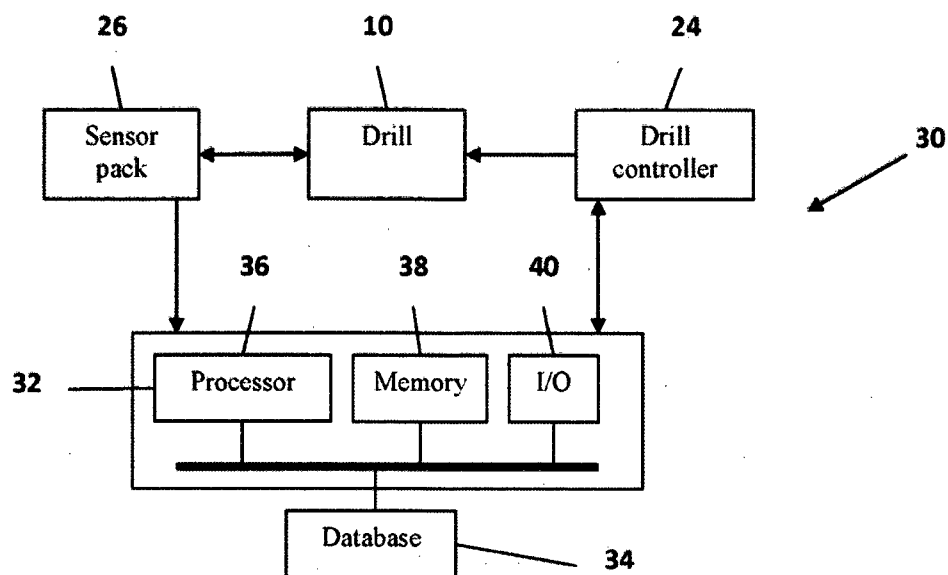
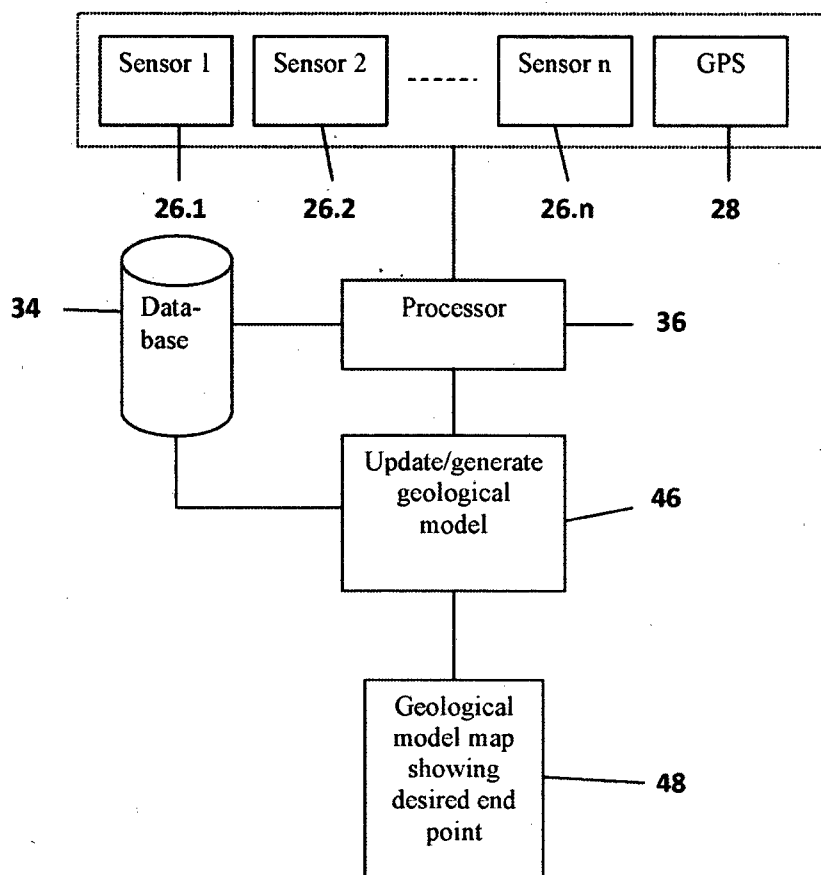
17. The system of any one of claims 11 to 16 in which the processor module is configured to update the geological model in real time on receipt of data from the sensor pack.

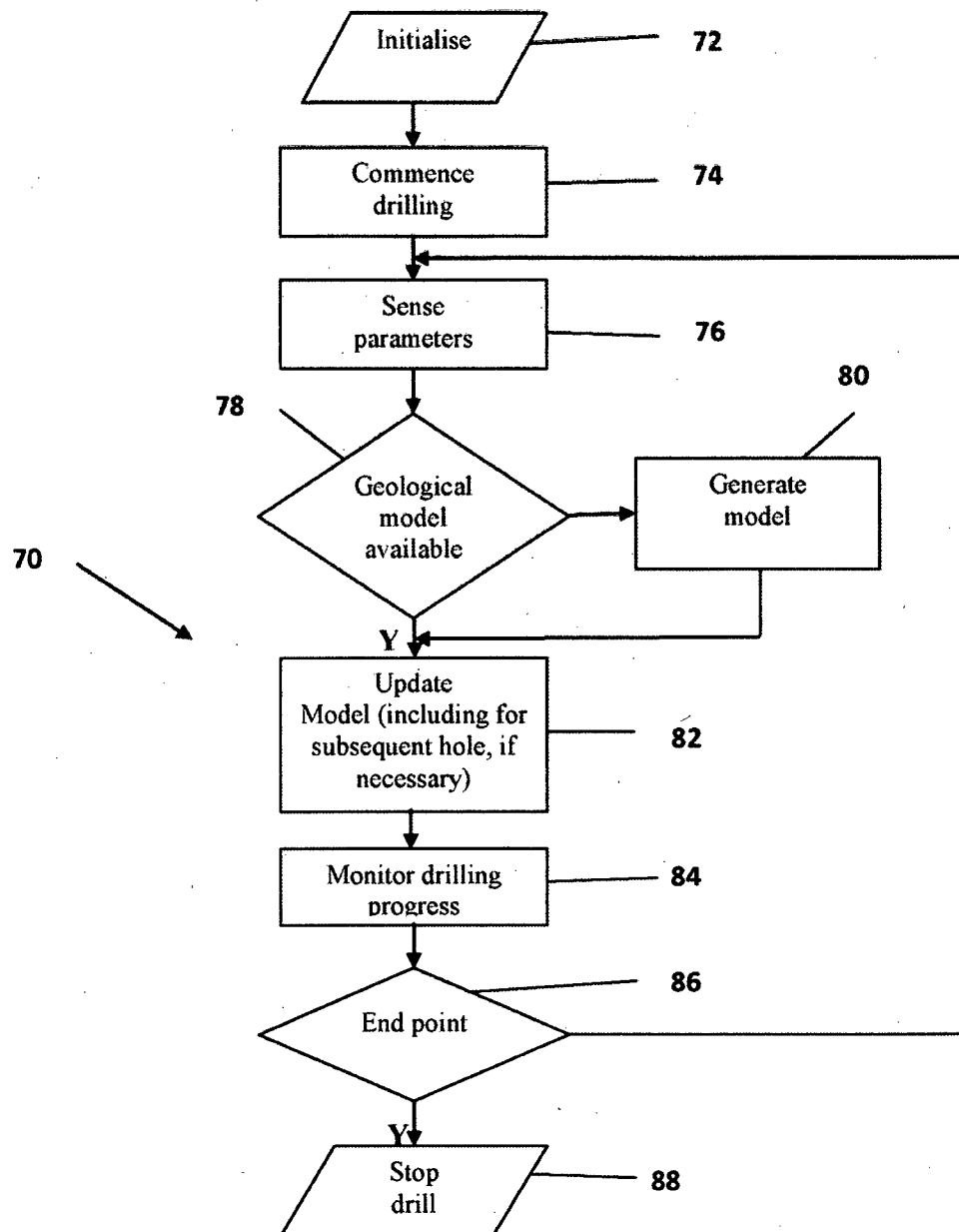
18. The system of any one of claims 11 to 17 in which the drill is an autonomous drill and the drill controller is operable under the action of the processor module to cease drilling when the end point has been reached.

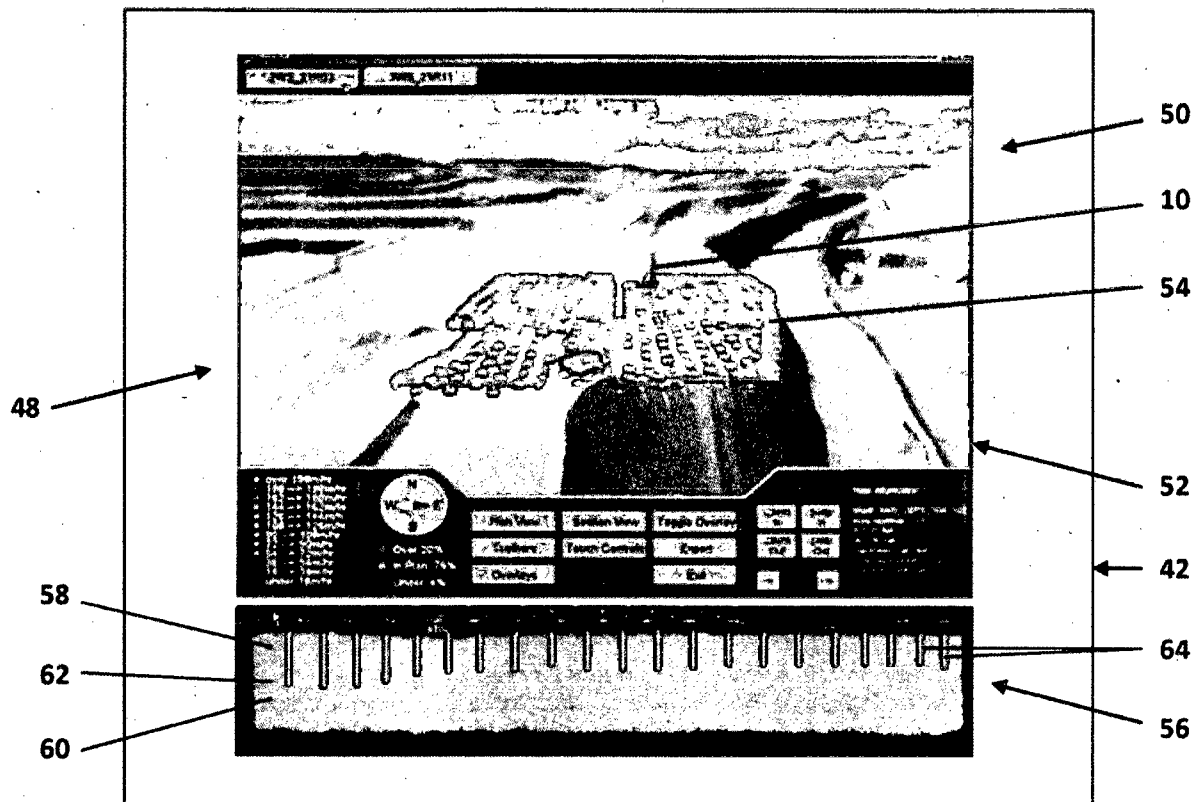
19. The system of any one of claims 11 to 17 in which the drill is an operator-controlled drill and the controller is responsive to commands from the operator to cease drilling when the end point has been reached.
20. A system for drilling to a position relative to a geological boundary in a geological formation, the system including
- a sensor pack for sensing parameters associated with a drilling operation carried out in the geological formation by a drill;
  - a data storage module for storing a geological model of the geological formation including the geological boundary, the data storage module further storing an end point arranged at a defined position relative to the geological boundary;
  - a processor module configured to monitor the drilling operation;
  - a drill controller in communication with the processor module, the drill controller being configured to control operation of the drill and to cause the drill to cease drilling when the end point has been reached; and
  - the processor module further being configured to use the sensed parameters to update the end point for a subsequent hole to be drilled by the drill.
21. Software that, when installed on a computer, causes the computer to perform the method of any one of claims 1 to 10.
22. A drill which includes
- a drilling platform;
  - a support structure mounted on the platform;
  - a drilling mechanism displaceably supported by the support structure, the drilling mechanism terminating in a drill bit for drilling a borehole; and
  - a drill controller carried on the drilling platform, the drill controller being operative to control operation of the drilling mechanism and the drill controller further being responsive to commands to cease drilling when the drill bit reaches an end point arranged at a defined position relative to a geological boundary.
23. The drill of claim 22 which includes a sensor pack for sensing parameters relating to a drilling operation.



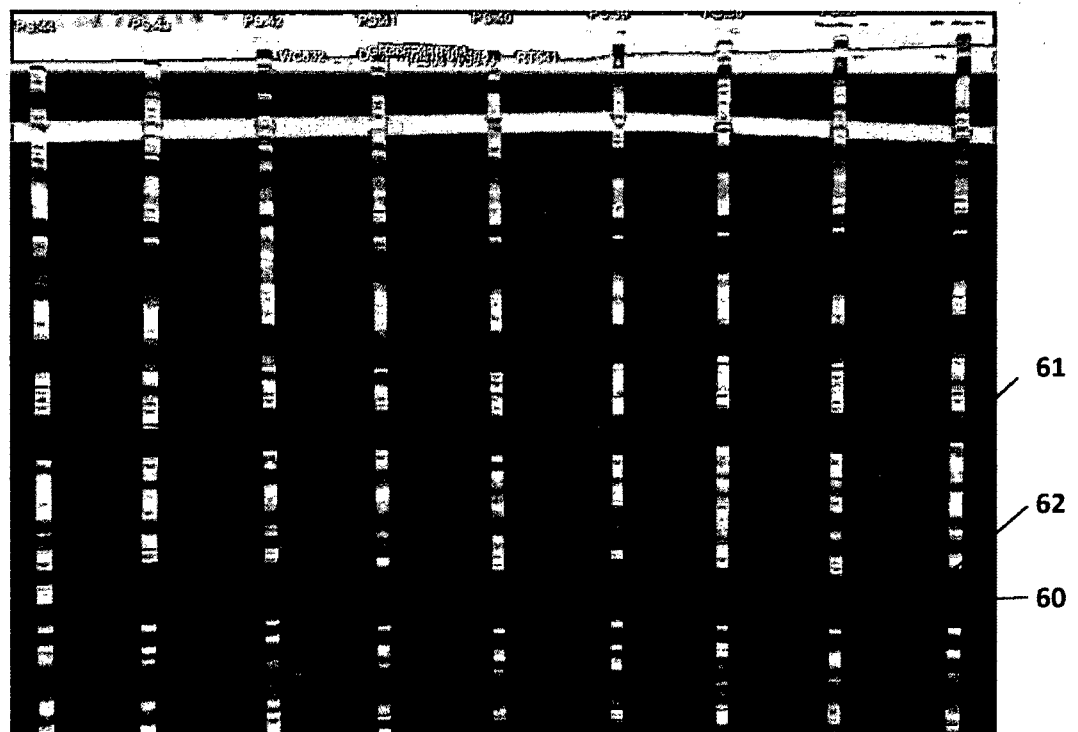
**Fig. 1**

**Fig. 2****Fig. 3**

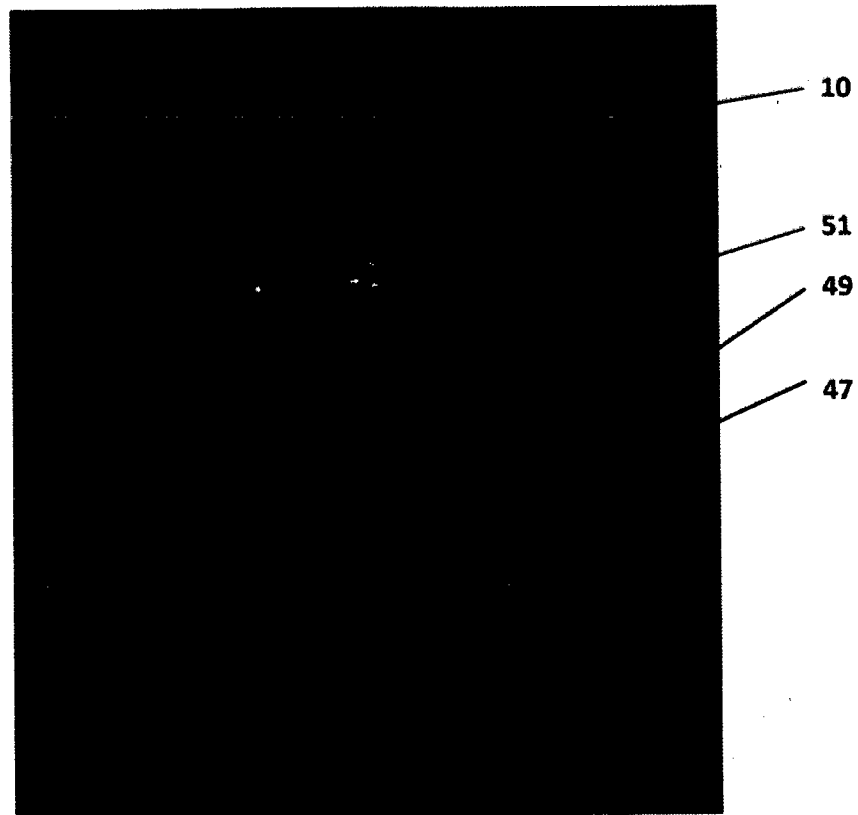
**Fig. 4**



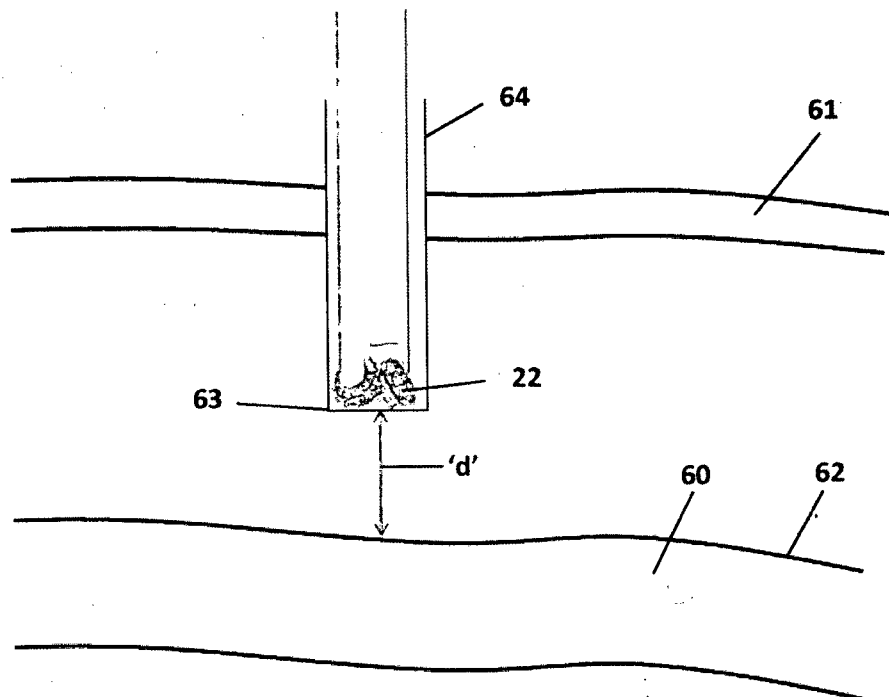
**Fig. 5**



**Fig. 6**



**Fig. 7**



**Fig. 8**

## INTERNATIONAL SEARCH REPORT

International application No.  
**PCT/AU2013/000734**

## A. CLASSIFICATION OF SUBJECT MATTER

**E21B 44/00 (2006.01) E21B 45/00 (2006.01) E21B 47/00 (2012.01) E21B 47/06 (2012.01) E21B 47/12 (2012.01)**  
**G01V 3/08 (2006.01) G01V 3/38 (2006.01) G06T 17/05 (2011.01)**

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

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

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)

WPI & EPODOC: IPC Marks, G06T17, G01V3, E21B44, E21B45, E21B47 & Keywords ( locate, distance, proximity, geological, model, detect, sense, determine, stop, cease, halt, boundary, interface, target, drill, bore and similar terms)

Google: Drill, position, geological model and similar terms or phrases

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|-----------|------------------------------------------------------------------------------------|-----------------------|
|           | Documents are listed in the continuation of Box C                                  |                       |

☒ Further documents are listed in the continuation of Box C ☒ See patent family annex

|          |                                                                                                                                                                     |     |                                                                                                                                                                                                                                              |
|----------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| *<br>"A" | Special categories of cited documents:<br>document defining the general state of the art which is not considered to be of particular relevance                      | "T" | later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention                                              |
| "E"      | earlier application or patent but published on or after the international filing date                                                                               | "X" | document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone                                                                     |
| "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) | "Y" | document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art |
| "O"      | document referring to an oral disclosure, use, exhibition or other means                                                                                            | "&" | document member of the same patent family                                                                                                                                                                                                    |
| "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  
2 October 2013

Date of mailing of the international search report  
02 October 2013

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| INTERNATIONAL SEARCH REPORT                           |                                                                                               | International application No. |
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| C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT |                                                                                               | PCT/AU2013/000734             |
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| X                                                     | WO 2010/132927 A1 (GEOMOLE PTY LTD) 25 November 2010<br>Figs 1-3c, Pages 1, 4-15              | 1-23                          |
| A                                                     | WO 2004/090285 A1 (BARKER HUGHES INCORPORATED) 21 October 2004<br>Abstract, Pages 1, 6-7      | 10 & 20                       |
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| A                                                     | WO 2011/094817 A1 (THE UNIVERSITY OF SYDNEY) 11 August 2011<br>whole document                 |                               |
| A                                                     | WO 2012/068629 A1 (TECHNOLOGICAL RESOURCES PTY. LIMITED et al.) 31 May 2012<br>whole document |                               |
| A                                                     | WO 2004/055325 A1 (CMTE DEVELOPMENT LIMITED) 01 July 2004<br>whole document                   |                               |
|                                                       |                                                                                               |                               |

**Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)**

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:  
because they relate to subject matter not required to be searched by this Authority, namely:
  
2. ☐ Claims Nos.:  
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
  
3. ☐ Claims Nos.:  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a)

**Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)**

This International Searching Authority found multiple inventions in this international application, as follows:

**See Supplemental Box for Details**

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☒ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
  
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

**Remark on Protest**

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

**Supplemental Box****Continuation of: Box III**

This International Application does not comply with the requirements of unity of invention because it does not relate to one invention or to a group of inventions so linked as to form a single general inventive concept.

This Authority has found that there are different inventions based on the following features that separate the claims into distinct groups:

- Claims 1-9, 11-19 & 21 are directed to a method and a system of drilling to a position relative to a geological boundary in a geological formation. The feature of using the sensed parameters and the geological model to locate the position of the drill bit of the drill relative to the geological boundary is specific to this group of claims.
- Claims 10, 20 are directed to a method and a system of drilling to a position relative to a geological boundary in a geological formation. The feature of updating the geological model using sensed parameters and/or updating the end point for subsequent hole to be drilled is specific to this group of claims.
- Claim 22-23 are directed to a drill. The feature of the means to cease drilling when the drill bit reaches an end point arranged at a defined position relative to a geological boundary is specific to this group of claims.

PCT Rule 13.2, first sentence, states that unity of invention is only fulfilled when there is a technical relationship among the claimed inventions involving one or more of the same or corresponding special technical features. PCT Rule 13.2, second sentence, defines a special technical feature as a feature which makes a contribution over the prior art.

When there is no special technical feature common to all the claimed inventions there is no unity of invention.

In the above groups of claims, the identified features may have the potential to make a contribution over the prior art but are not common to all the claimed inventions and therefore cannot provide the required technical relationship. The only feature common to all of the claimed inventions and which provides a technical relationship among them is the means to cease drilling when the drill bit reaches an end point arranged at a defined position relative to a geological boundary

However this feature does not make a contribution over the prior art because it is disclosed in:  
D1

Therefore in the light of this document this common feature cannot be a special technical feature. Therefore there is no special technical feature common to all the claimed inventions and the requirements for unity of invention are consequently not satisfied *a posteriori*.

| INTERNATIONAL SEARCH REPORT                                                                                                                                                                                                                                           |                  | International application No. |                  |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|-------------------------------|------------------|
| Information on patent family members                                                                                                                                                                                                                                  |                  | PCT/AU2013/000734             |                  |
| This Annex lists known patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information. |                  |                               |                  |
| Patent Document/s Cited in Search Report                                                                                                                                                                                                                              |                  | Patent Family Member/s        |                  |
| Publication Number                                                                                                                                                                                                                                                    | Publication Date | Publication Number            | Publication Date |
| WO 2010/132927 A1                                                                                                                                                                                                                                                     | 25 Nov 2010      | None                          |                  |
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| WO 2004/055325 A1                                                                                                                                                                                                                                                     | 01 Jul 2004      | WO 2004055325 A1              | 01 Jul 2004      |
| End of Annex                                                                                                                                                                                                                                                          |                  |                               |                  |
| Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.                                                                                                                                             |                  |                               |                  |