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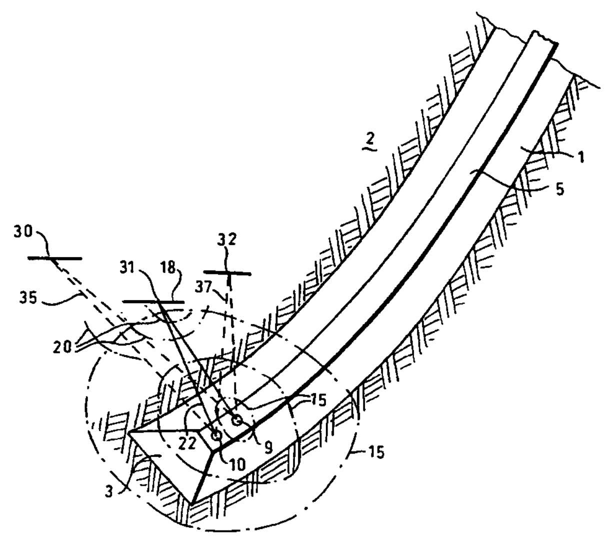
(54) Title: OBTAINING AN IMAGE OF AN UNDERGROUND FORMATION



(57) **Abstract:** An image of an underground formation (2) around a borehole (1) is obtained by activating an omnidirectional source (9) and recording with a three-component receiver (10) the components of the reflected energy (15); determining therefrom the components the directions from which the energy arrives at the three-component receiver (10) as a function of two-way travel time; selecting a first underground position (30); assuming a reflector to be present at position (30) and calculating the arrival direction of a ray (35) extending from the source (9) via the reflector (30) to the receiver (10) and two-way travel time along the ray (35); accepting the data if the calculated arrival direction is substantially equal to an arrival direction that has the same two-way travel time, and attributing the data on the position (30); and selecting a next position (31 or 32) and repeating steps (e) and (f) until the last underground position to obtain the image of the underground formation comprising a set of reflectors attributed to positions.

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OBTAINING AN IMAGE OF AN UNDERGROUND FORMATION

The present invention relates to a method of obtaining an image of an underground formation around a borehole extending through the underground formation. The image that is to be obtained comprises a set of reflectors attributed to underground positions in the underground formation around the borehole. Such an image is produced to provide detailed information of the underground formation while drilling the borehole. This information allows planning the direction into which the borehole is drilled. This is particularly useful when it is required that a horizontal borehole that is being drilled is kept within a thin formation layer.

USA patent specification No. 5 300 929 relates to a method of delineating an interface between a salt and a sediment. The known method comprises

(a) arranging an omnidirectional source at the surface and fixedly arranging a three-component receiver in a borehole that extends through the salt;

(b) activating the omnidirectional source to generate seismic energy and recording with the three-component receiver data in the form of the components of the seismic energy;

(c) determining from the components of the seismic energy the directions from which the seismic energy arrives at the three-component receiver as a function of travel time;

(d) accepting a point as being located at the interface if the ray extending through the point has the corresponding travel time; and

(e) selecting a new surface position for the omni-directional source, and repeating steps (b)-(d).

The known method is applied to determine the boundary between a salt dome and sediment surrounding the salt dome, wherein the borehole is drilled into the salt dome. Because the omnidirectional source and the three-component receiver are spaced apart at either side of the boundary, the seismic energy passes through the underground formation.

It is an object of the present invention to provide a method for obtaining an image of the underground formation using an omnidirectional source and an three-component receiver that are both located in a borehole extending through the underground formation, which allows imaging reflectors that reflect the seismic energy emitted by the omnidirectional source, wherein the position of the reflectors can be anywhere around the borehole.

To this end the method of obtaining an image of an underground formation around a borehole extending through the underground formation according to the present invention comprises the steps of

(a) selecting a number of positions for an omni-directional source and a three-component receiver in the borehole, selecting a number of underground positions in the formation, and attributing a value of zero to the underground positions;

(b) arranging an omnidirectional source and a three-component receiver in a first position in the borehole;

(c) activating the omnidirectional source to generate seismic energy and recording with the three-component receiver data in the form of the components of the reflected seismic energy;

(d) determining from the components of the reflected seismic energy the directions from which the reflected seismic energy arrives at the three-component receiver as a function of two-way travel time;

(e) selecting a first underground position;

(f) calculating the arrival direction of a ray extending from the omnidirectional source to the underground position and back to the three-component receiver and the two-way travel time of seismic energy passing along the ray;

(g) accepting the data if the calculated arrival direction is substantially equal to an arrival direction as obtained in step (d) pertaining to reflected seismic energy having the same two-way travel time, and adding the accepted data to the value attributed to the underground position;

(h) selecting a next underground position and repeating steps (f) and (g) until the last underground position; and

(i) arranging the omnidirectional source and the three-component receiver in a next position in the borehole, and repeating the steps (b) through (h) until the last position along the borehole to obtain the image of the underground formation comprising a set of data mapped on underground positions.

In the specification and in the claims the term 'two-way travel time' is used to refer to the time it takes for seismic energy to go from a source via a reflector to a receiver.

It will be understood that in order to perform the calculations in step (f), it is required to know the seismic velocities in the formation. These seismic velocities can be obtained from previous seismic work done in relation to the formation, or they can be obtained from core samples. In addition, sonic measurements can provide information on the seismic velocities.

The invention will now be described by way of example in more detail with reference to the accompanying Figure.

In the Figure is shown the lower end of a borehole 1 that is being drilled in an underground formation 2. In this example the borehole 1 is drilled by means of a drill bit 3 suspended in the borehole by means of a drill string assembly 5, which drill string assembly 5 is rotated.

Near the drill bit 3, the drill string assembly 5 comprises an omnidirectional source 9 and a downhole three-component receiver 10.

During normal operation, the drill bit 3 is used to drill the borehole 1, and in order to obtain the image, drilling is interrupted, and the omnidirectional source 9 is activated. Seismic energy emitted by the omni-directional source 9 spreads out into the formation 2, and the wave fronts pertaining to the reflected seismic energy at different moments in time are schematically shown by the dashed lines 15.

Assume that a reflector 18 is present in the underground formation 2, which reflector 18 reflects the seismic energy. The wave fronts pertaining to the reflected seismic energy at different moments in time are schematically shown by the dashed lines 20. Line 22 represents a ray extending from the omnidirectional source 9 to the reflector 18 and back to the three-component receiver 10.

The data received by the three-component receiver 10 includes the components of the reflected seismic energy in time. From this data the directions from which the seismic energy arrives can be determined as a function of the two-way travel time.

Next a number of underground positions 30, 31 and 32 are selected in the formation, and a first one is chosen, let us assume that it is underground position 30. Knowing the seismic velocities in the underground formation, the arrival direction of the ray extending from the omnidirectional source 9 to the reflector at position 30 and back to the three-component receiver 10 is calculated as well as the two-way travel time of seismic energy passing along the ray. This ray is shown by dashed line 35.

The data is accepted if the calculated arrival direction is substantially equal to an arrival direction that has the same two-way travel time. In this example, this is clearly not the case for underground position 30, so that the data is not accepted.

Then a next underground position 31 is selected. Next the arrival direction of the ray extending from the omnidirectional source 9 to the reflector at position 31 and back to the three-component receiver 10 is calculated as well as the two-way travel time of seismic energy passing along the ray. This ray coincides with line 22. In this case the calculated arrival direction is substantially equal to the arrival direction of the reflection from the reflector 18, and the ray that coincides with line 22 has the same two-way travel time. Thus the data is accepted and the accepted data are added to the value attributed to the underground position 31. This adding is also referred to as migration.

Then the third underground position 32 is selected. The calculated arrival direction of the ray extending from the omnidirectional source 9 to the reflector at position 32 and back to the three-component receiver 10 shown as dashed line 37 is not substantially equal to the arrival direction of the reflection from the reflector 18. Thus the data is not accepted.

Having treated the three underground positions 30, 31 and 32, an image of the underground formation 2 is obtained, which image comprises a reflector attributed to underground position 31 and no reflectors attributed to underground positions 30 and 32.

Drilling is resumed, and after some distance has been drilled the above described procedure is repeated, and so on.

In this way an accurate image of the underground formation near the drill bit can be obtained, in particular when more than three underground positions are selected for each position along the borehole.

In case there are more reflectors than the reflector 18 shown in the Figure, rays from these reflectors (not shown) will be received at different moments in time.

Determining from the components of the reflected seismic energy the directions from which the reflected seismic energy arrives at the three-component receiver as a function of two-way travel time is known, it can for example be done with techniques outlined in the article 'Comparison of signal processing techniques for estimating the effects of anisotropy' by C Macbeth and S Crampin, Geophysical Prospecting, 39, 1991, pages 357-385.

The data is accepted if the calculated arrival direction is substantially equal to an arrival direction that has the same two-way travel time. To do so, suitably, the difference between the calculated arrival direction and the arrival direction pertaining to reflected seismic energy having the same two-way travel time is determined. Then a weight factor is determined using a predetermined function of this difference. The data are multiplied with the weight factor, and the weighted data are mapped on the underground position. The weight function is for example a rectangular window function. The window function or box function is a function of the difference, such that the window function equals 1 if the absolute value of the difference is less than a predetermined value and that it equals 0 everywhere else. Consequently for a large difference the weight factor is 0 and the weighted data is 0 so that no data are mapped, and for a relatively small difference the weight factor is 1 so that the data are mapped. An alternative weight function is a cosine squared.

Suitably, the data that is mapped on the underground position is the magnitude of the reflected seismic energy, which is the sum of the components of the reflected seismic energy or the square root of the sum of the squares of the components of the reflected seismic energy. The magnitude of the reflected seismic energy is then determined with the migration technique. Alternatively, the reflectivity can be determined from the data by comparing the reflected seismic energy with the emitted seismic energy and making a correction for the geometrical spreading.

Although it is possible to apply the migration technique for any position of the omnidirectional source relative to the three-component receiver, it is preferred that the omnidirectional source and the three-component receiver are coincident. In the specification and in the claims the word 'coincident' is used as follows. Two devices are said to be coincident when they are as close to each other as is technically feasible, in which case they can be considered as one for calculation purposes. In that case the reflectivity can be calculated using a zero-offset migration algorithm.

In order to distinguish the arrival of shear waves (or s waves) from the arrival of faster compression waves (or p waves), a sensor, such as a hydrophone or an accelerometer can be included in the three-component receiver.

The reflected seismic energy can be passed to surface by known means of transferring data, so that the analysis part of the method is done at surface. Alternatively, the directions from which the reflected seismic energy arrives at the three-component receiver as a function of two-way travel time are determined in-situ, and the results are transferred to surface where the analysis takes place.

Instead of using an omnidirectional separate source, the drill bit itself can be used as a source, and in that case the seismic energy is the noise generated while drilling.

The present invention provides a simple method for obtaining an image from an underground formation in the neighbourhood of a borehole that is being drilled.

C L A I M S

1. A method of obtaining an image of an underground formation around a borehole extending through the underground formation, which method comprises the steps of

(a) selecting a number of positions for an omnidirectional source and a three-component receiver in the borehole, selecting a number of underground positions in the formation, and attributing a value of zero to the underground positions;

(b) arranging an omnidirectional source and a three-component receiver in a first position in the borehole;

(c) activating the omnidirectional source to generate seismic energy and recording with the three-component receiver data in the form of the components of the reflected seismic energy;

(d) determining from the components of the reflected seismic energy the directions from which the reflected seismic energy arrives at the three-component receiver as a function of two-way travel time;

(e) selecting a first underground position;

(f) calculating the arrival direction of a ray extending from the omnidirectional source to the underground position and back to the three-component receiver and the two-way travel time of seismic energy passing along the ray;

(g) accepting the data if the calculated arrival direction is substantially equal to an arrival direction as obtained in step (d) pertaining to reflected seismic energy having the same two-way travel time, and adding the accepted data to the value attributed to the underground position;

(h) selecting a next underground position and repeating steps (f) and (g) until the last underground position; and

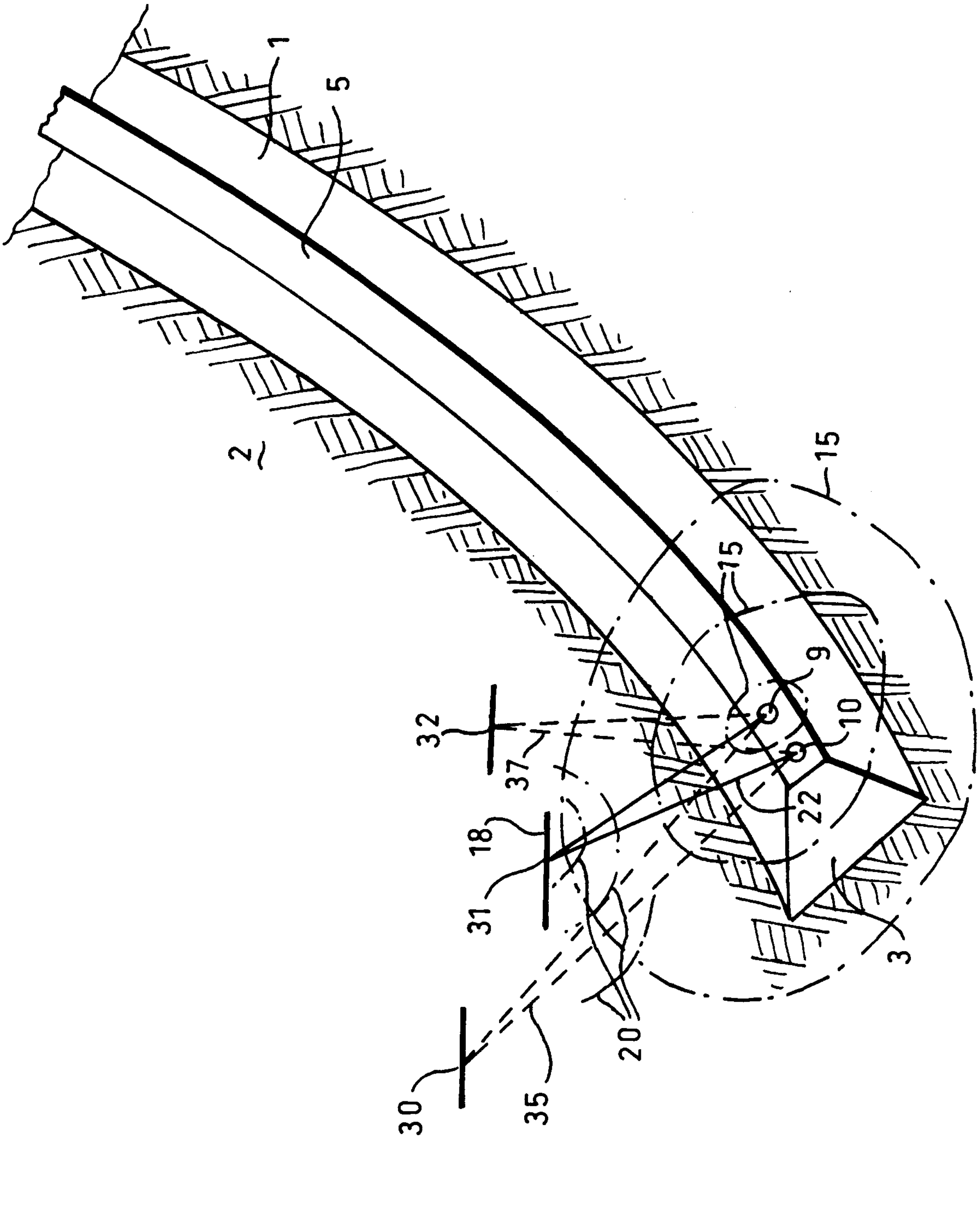
(i) arranging the omnidirectional source and the three-component receiver in a next position in the borehole, and repeating the steps (b) through (h) until the last position along the borehole to obtain the image of the underground formation comprising a set of data mapped on underground positions.

2. The method according to claim 1, wherein step (g) comprises determining the difference between the calculated arrival direction and the arrival direction as obtained in step (c) pertaining to reflected seismic energy having the same two-way travel time, multiplying the data with a weight factor which is a predetermined function of this difference, and mapping the weighted data on the underground position.

3. The method according to claim 1 or 2, wherein the data used in step (g) is the sum of the components of the reflected seismic energy recorded in step (c).

4. The method according to any one of the claims 1-3, wherein the omnidirectional source and the three-component receiver are coincident.

5. The method according to any one of the claims 1-4, wherein the three-component receiver further includes a pressure sensor.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INTERNATIONAL SEARCH REPORT

Inter. ɔnal Application No
PCT/EP 00/10080

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01V1/50

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)
IPC 7 G01V

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 practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC, COMPENDEX

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5 300 929 A (MACLEOD MARK K) 5 April 1994 (1994-04-05) column 1, line 5 - line 12 column 3, line 45 - line 68 column 4, line 23 - line 36 column 5, line 14 -column 6, line 8 ---	1,4,5
Y	WO 99 19749 A (INPUT OUTPUT INC) 22 April 1999 (1999-04-22) page 1, line 1 - line 11 page 2, line 10 -page 3, line 8 page 5, line 11 -page 6, line 18 page 9, line 14 -page 10, line 9; claim 1 --- -/--	1,4,5

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
31 January 2001	08/02/2001

Name and mailing address of the ISA	Authorized officer
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INTERNATIONAL SEARCH REPORT

Interı nal Application No
PCT/EP 00/10080

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 170 377 A (MANZUR AKKAS ET AL) 8 December 1992 (1992-12-08) column 1, line 10 - line 15 column 4, line 18 - line 36 column 5, line 33 -column 6, line 60 ---	1
A	US 5 081 611 A (HORNBY BRIAN E) 14 January 1992 (1992-01-14) column 1, line 10 - line 15 column 4, line 33 -column 5, line 35; claim 1 -----	1,2

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/EP 00/10080

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US 5300929 A	05-04-1994	NONE	
WO 9919749 A	22-04-1999	US 6023657 A AU 8675998 A	08-02-2000 03-05-1999
US 5170377 A	08-12-1992	NONE	
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