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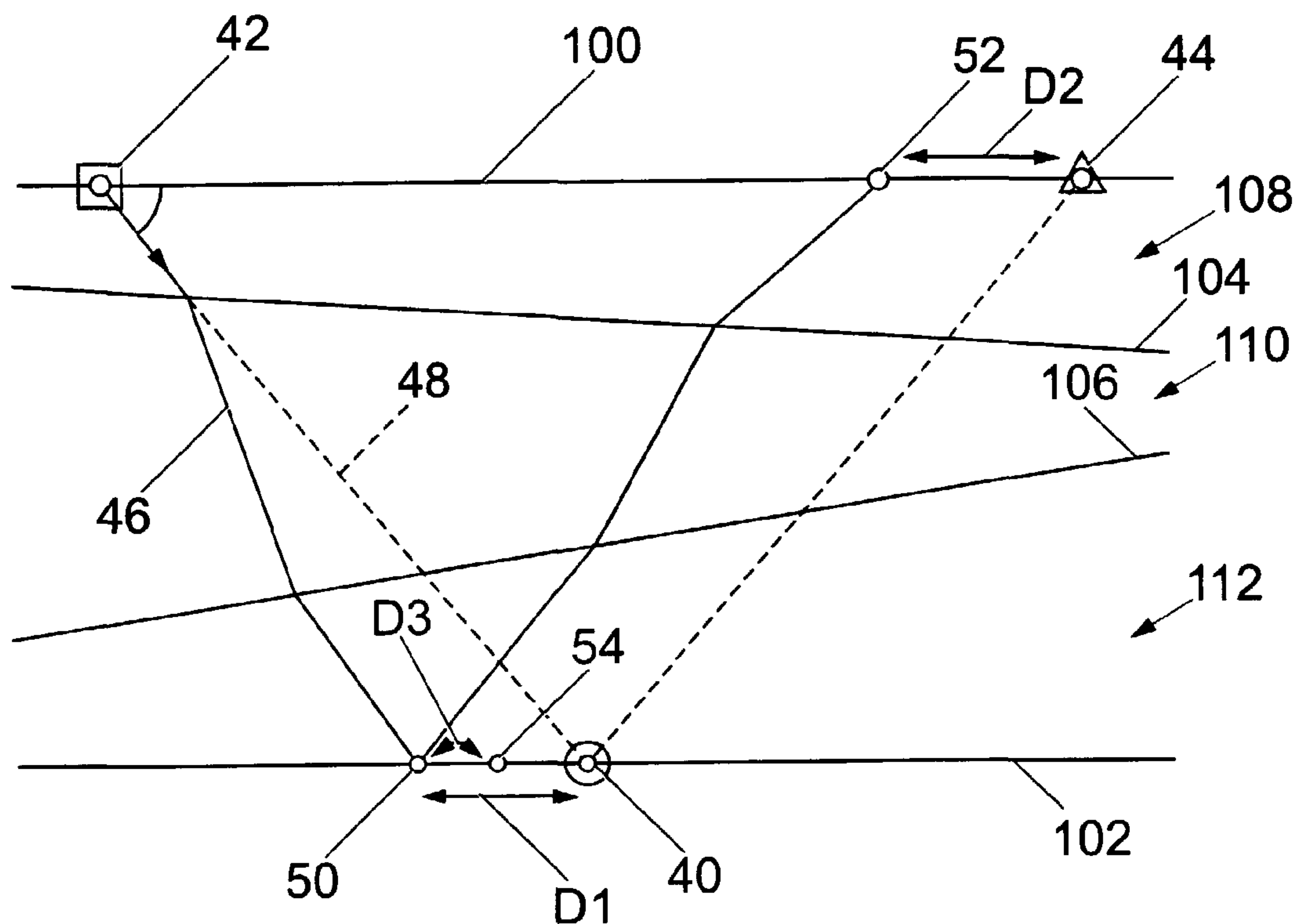
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(54) Title: SEISMIC SURVEY SYSTEM



(57) Abrégé/Abstract:

A method of analysing seismic survey data in which a transfer function for a geological model is derived by ray tracing techniques applied to theoretical data and the transfer function is applied to actual survey data in order to calculate reflection points (50) and/or other attributes for each shot (42)/receiver (44) pair. The number of ray tracing calculations which have to be performed in deriving the model transfer function can thus be controlled. A sufficiently accurate transfer function can be derived using theoretical data representing substantially fewer shot (42)/receiver (44) pairs than are used in the traditional ray tracing solution applied directly to actual survey data. Attribute values for actual source (42)/receiver (44) pairs are estimated by interpolating the transfer function data.

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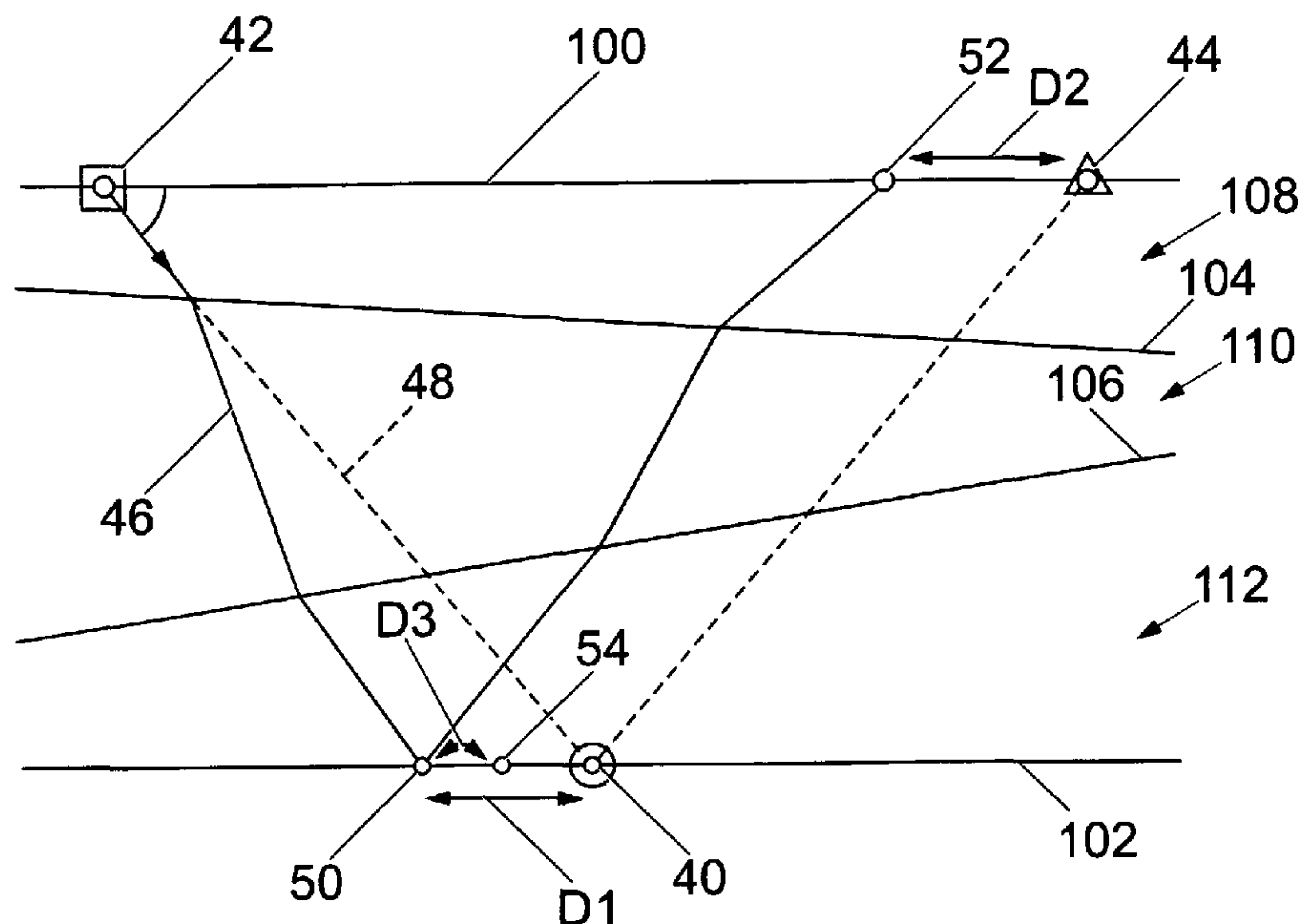
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1 Seismic Survey System

2

3 The present invention relates to seismic survey
4 systems and methods of analysing seismic survey
5 data.

6

7 During seismic survey operations, a source of energy
8 is fired into the ground by a source at a particular
9 location, a single instance of this being known as a
10 "shot". The energy propagates as a pressure wave
11 and shear wave through the ground and is reflected
12 from structures in the underlying geology. The
13 reflected return energy is measured by an array of
14 sensors ("receivers") deployed at known positions.
15 The collected measurements of return energy are
16 referred to hereinafter as "data". The process is
17 repeated over some form of regular grid 10 (see
18 Figure 1 of the accompanying drawings), each cell 12
19 of the grid being known as a "bin". For each
20 shot/receiver pair, the data from the receiver is
21 used to calculate a corresponding subsurface
22 position ("reflection point") between the shot

1 location and the receiver position, from which the
2 shot energy is deemed to have been reflected. The
3 calculated reflection points associated with the
4 data are mapped over the survey area to produce a
5 plot known as a coverage map. This map is used to
6 identify areas that are less well covered by data
7 and which require more shots in order to acquire
8 further data. Accordingly, this may have a major
9 impact on the overall cost of the survey.

10

11 As is also shown in Figure 1, the intended shot
12 locations for a particular survey operation are
13 arranged along survey lines 14. Generally speaking,
14 analysis of initial survey data will reveal faults,
15 gaps etc. in this primary data, and additional shots
16 will be required, arranged along "infill" lines 16.

17

18 The present invention is concerned with the problem
19 of calculating the reflection points and/or other
20 attributes used to map the data. In the simplest
21 case (referring now to Figure 2), the reflection
22 point may be assumed to be at the mid-point 18
23 between the shot source 20 and the receiver 22.

24 This has the advantage of speed and simplicity, but
25 is necessarily only a crude approximation, taking no
26 account of the underlying geology, typically
27 comprising a number of layers 24, 26, 28 having
28 differing properties, which affects the propagation
29 paths between the shot location 20 and the receiver
30 positions 22. Consequently, this method generally
31 results in too much data being mapped in some areas
32 and too little in other areas. Nevertheless, for a

1 number of practical reasons, this is the primary
2 method currently employed in the industry.

3

4 A more accurate estimate of the reflection point can
5 be obtained by calculating the propagation paths 30,
6 and hence the reflection point 32, on the basis of
7 existing knowledge of the subsurface geology, as is
8 also illustrated in Figure 2. In principal, this
9 approach ("ray tracing") allows the reflection point
10 32 to be calculated with a high degree of precision.
11 However, a significant problem with this approach is
12 that the starting angle (α) of a particular ray
13 originating at the shot location 20 which will cause
14 the ray to emerge at the receiver position 22 is
15 unknown. Figure 2 shows a simplified example in
16 only two dimensions, showing only the vertical
17 offset angle (α). In practice it is also necessary
18 to take account of the horizontal azimuth angle (β).
19 The problem becomes more complicated and time
20 consuming with complex three-dimensional geologies.

21

22 The standard solution for ray tracing methods of
23 this type is, for each shot/receiver pair, to
24 iterate through many possible starting angles until
25 a result is obtained which is close to the receiver
26 position (within pre-defined tolerances). This
27 standard approach is extremely inefficient,
28 requiring many calculations to be performed and
29 discarded before a useful result is obtained. The
30 approach has two basic problems:

31

1 A. The number of computations required is the
2 product of the number of shots, the number of
3 receivers and the number of iterations. Given that
4 a typical survey will involve 50-1000 million
5 shot/receiver pairs, it is extremely important that
6 the number of iterations is kept as low as possible.
7 There are a number of techniques which allow the
8 starting angle (α) to be estimated, allowing the
9 number of iterations to be minimised. Even in the
10 simplest case (given a single flat layer; i.e. the
11 mid-point reflection case), however, this still
12 requires a number of computations equal to the
13 product of the number of shots and the number of
14 receivers.

15
16 B. This technique also makes the assumption that
17 each shot/receiver pair has a unique solution, and
18 that the level of detail (and hence the number of
19 calculations required) is governed only by the
20 density of shot/receiver pairs and not by the
21 resolution of the geological model.

22
23 The present invention seeks to provide improved
24 seismic survey systems and methods of analysing
25 seismic survey data which obviate or mitigate the
26 aforesaid disadvantages.

27
28 The present invention is based on two assumptions:
29 - firstly, that any geological model employed
30 for the purpose of analysing seismic survey data
31 will have a fixed and predictable effect on the
32 data, and that this effect can be described by a

1 transfer function which may be determined by ray
2 tracing techniques applied to a relatively small set
3 of hypothetical shot/receiver locations; and

4 - secondly, that once the transfer function of
5 the model is known, the transfer function can be
6 applied to the actual shot/receiver pair data in
7 order to determine the reflection points and/or
8 other attributes to an acceptable degree of accuracy
9 with no or minimal additional ray tracing (in areas
10 where the geology is changing rapidly, some
11 additional ray tracing may be required during the
12 calculation of the transfer function, which may be
13 performed automatically).

14

15 The preferred embodiments of the invention involve a
16 two stage process in which a transfer function for a
17 geological model is derived by ray tracing
18 techniques applied to theoretical data and the
19 transfer function is applied to actual survey data
20 in order to calculate reflection points and/or other
21 attributes for each shot/receiver pair. The number
22 of ray tracing calculations which have to be
23 performed in deriving the model transfer function
24 can thus be controlled. It has been found that a
25 sufficiently accurate transfer function can be
26 derived using theoretical data representing
27 substantially fewer shot/receiver pairs than are
28 used in the traditional ray tracing solution applied
29 directly to actual survey data.

30

1 In accordance with a first aspect of the present
2 invention, there is provided a method of analysing
3 seismic survey data, comprising:

4 (a) obtaining a numerical model describing the
5 geology of a survey area;

6 (b) calculating a transfer function for said model
7 which defines at least one attribute value within
8 said survey area for a set of hypothetical shot
9 source locations and corresponding receiver
10 locations;

11 (c) comparing a set of actual survey data
12 comprising a plurality of source/receiver pairs with
13 said set of hypothetical source locations and
14 receiver locations, and estimating at least one
15 actual attribute value for each of said
16 source/receiver pairs on the basis of said
17 comparison.

18

19 Preferably, the step (b) includes:

20 (d) selecting a set of initial points within said
21 survey area and selecting at least one hypothetical
22 source location and a corresponding hypothetical
23 receiver location centred on each of said points;

24 (e) for each of said source locations, calculating
25 the path of a ray through said model originating at
26 said source location and having an initial direction
27 towards said initial point so as to determine a
28 reflection point and an emergence point for said
29 ray.

30

31 Preferably, the step of calculating said transfer
32 function further includes:

1 (f) for each of said source locations, calculating
2 a distance D1 between said initial point and said
3 reflection point, a distance D2 between said
4 hypothetical receiver location and said emergence
5 point, a mid-point between said hypothetical shot
6 location and said emergence point, and a distance D3
7 between said mid-point and said initial point;
8 (g) where said distance D2 exceeds a predetermined
9 minimum value, selecting a second hypothetical
10 receiver location on the basis of said distance D3
11 and repeating steps (e) and (f) for said second
12 hypothetical receiver location.

13

14 Preferably:

15 (h) where a new value of D3 calculated in step (g)
16 remains greater than said predetermined minimum
17 value, the method includes performing further
18 iterations of step (g) in which further hypothetical
19 receiver locations are selected based on a weighted
20 average of the distance D3 obtained in previous
21 iterations until a value of distance D3 is obtained
22 which does not exceed said predetermined value.

23

24 Preferably, the method further includes:

25 (i) dividing said survey area into a plurality of
26 first blocks, said initial points selected in step
27 (c) comprising central points of said first blocks.

28

29 Preferably, the method further includes:

30 (j) sub-dividing each of said first blocks into a
31 plurality of second blocks, selecting a second set
32 of initial points comprising central points of said

1 second blocks, and repeating said steps (d) and (e)
2 for said second set of initial points.

3

4 Preferably, the method further includes:

5 (k) repeating said steps (f) to (h) for said second
6 set of initial points.

7

8 Preferably, the method further includes:

9 (l) successively sub-dividing each of said blocks
10 into further blocks and repeating steps (j) and (k)
11 for said further blocks until the difference between
12 values of distance D3 calculated for successive
13 blocks does not exceed a predetermined value.

14

15 Preferably, said transfer function comprises a
16 database of hypothetical source locations, receiver
17 locations and corresponding values of at least one
18 attribute.

19

20 Preferably, said step (c) comprises:

21 (m) applying a matching algorithm to said actual
22 survey data and said set of hypothetical source
23 locations and receiver locations so as to select a
24 subset of said hypothetical source locations and
25 receiver locations and calculating at least one
26 estimated attribute value for each of said
27 source/receiver pairs, on the basis of transfer
28 function data associated with subset of said
29 hypothetical source locations and receiver
30 locations.

31

32

1 Preferably, said estimated attribute values are
2 calculated by interpolating transfer function data
3 associated with said subset of hypothetical source
4 locations and receiver locations.

5

6 Preferably, said at least one attribute includes at
7 least one of: reflection point, deviation between
8 mid-point and reflection point, travel time,
9 amplitude and incidence angle.

10

11 In accordance with a second aspect of the invention,
12 there is provided a seismic survey method comprising
13 obtaining a set of seismic survey data for a survey
14 area and analysing said seismic survey data using a
15 method in accordance with the first aspect of the
16 invention.

17

18 In accordance with a third aspect of the invention,
19 there is provided a computer program or a suite of
20 computer programs adapted to execute the method in
21 accordance with the first aspect of the invention.

22

23 In accordance with a fourth aspect of the invention,
24 there is provided a data processing system adapted
25 to execute one or more computer programs in
26 accordance with the third aspect of the invention.

27

28 In accordance with a fifth aspect of the invention,
29 there is provided a data carrier encoded with one or
30 more computer programs in accordance with the third
31 aspect of the invention.

32

1 Embodiments of the invention will now be described,
2 by way of example only, with reference to the
3 accompanying drawings, in which:

4

5 Figure 1 is a schematic plan view illustrating the
6 basic methodology of a seismic survey operation;

7

8 Figure 2 is a schematic, sectional side view of a
9 geological structure illustrating the propagation of
10 energy between a shot source and a receiver;

11

12 Figure 3 is a first diagram illustrating the manner
13 in which a transfer function for a geological model
14 is derived in accordance with one embodiment of the
15 invention;

16

17 Figure 4 is a second diagram illustrating the manner
18 in which a transfer function for a geological model
19 is derived in accordance with one embodiment of the
20 invention.

21

22 The systems and methods of the present invention
23 involve a two stage methodology, a first "model
24 processing" stage and a second "ray matching"
25 procedure.

26

27 Referring firstly to model processing, the type of
28 subsurface model is chosen to optimise computational
29 speed. Preferably, this comprises a layered model,
30 with fully defined boundaries between the layers.

31 Such a model defines the three-dimensional structure
32 of the geology in terms of layers, boundaries

1 between layers, and outermost surface and sub-
2 surface boundaries. The boundaries are defined by a
3 plurality of faces and each face by a plurality of
4 polygons, suitably triangles.

5
6 The model further defines the properties of the
7 layers and boundary faces which determine the path
8 of a ray passing through the structure. Typically,
9 a boundary face will be reflective, refractive,
10 absorbent or have a "conversion" property
11 (reflection/refraction with a change of wave type).
12 The model further defines a pressure wave velocity
13 profile for each layer, which may be, for example, a
14 constant velocity or a velocity which varies
15 linearly as a function of depth, or a velocity which
16 varies in some other manner. Shear wave velocity
17 profiles may also be defined, possibly comprising a
18 function of the pressure wave velocity. Density
19 profiles may also be defined for layers. Where the
20 reflection/refraction/absorption properties of a
21 face are unknown, the effect of the face on a ray
22 may be calculated on the basis of the impedance of
23 the adjacent layers, which in turn may be derived
24 from the velocity and density parameters of the
25 layers.

26
27 Using a model of this type, the calculation of a ray
28 path through the model is quite straightforward.
29 Given a starting (shot) location (normally but not
30 necessarily on the surface of the model) and
31 direction (typically defined by the offset and
32 azimuth angles α and β), it is possible to determine

1 the point at which the ray will intersect the next
2 boundary. After hitting a boundary face, the next
3 direction of the ray may be determined from the
4 properties of the face and/or adjacent layers and
5 the point of intersection with the next boundary
6 face may be determined, this process being repeated
7 until the ray exits the model through one of the
8 outermost boundaries. The parameters defined by the
9 model also allow travel times and/or signal
10 amplitudes and/or other attributes to be calculated.
11

12 Travel times can be calculated in a straightforward
13 manner based on the parameters of the model.
14 Changes in signal amplitude (attenuation) can also
15 be calculated.
16

17 The model is used to generate a database of ray
18 paths between a plurality of shot locations and
19 receiver positions. This database effectively
20 constitutes a transfer function for the model. The
21 database is generated as follows, with reference to
22 Figure 3, which illustrates a portion of a
23 simplified example of a geological model having top
24 and bottom boundaries 100 and 102, and inter-layer
25 boundaries 104 and 106 between layers 108, 110 and
26 112. For present purposes, the bottom boundary 102
27 is taken as the average depth of the actual bottom
28 boundary of the model. It will be understood that
29 the top boundary 100 will not generally be flat, and
30 height differences between the shot and receiver
31 positions are also taken into account in the
32 calculations described below.

1
2 In general, the user will have some prior knowledge
3 regarding the typical offsets and azimuths in a
4 survey (in this context, offset means the distance
5 between a source and a receiver). Most offsets and
6 azimuths will be relatively close to one another.
7 Therefore, rather than computing ray paths for every
8 possible offset/azimuth pair, the user may select a
9 set of typical offsets and azimuths. The system may
10 provide a set of pre-defined templates for this
11 purpose.

12
13 A first set of points is selected within the survey
14 area and each of these points is treated as the mid-
15 point (40 in Figure 3) between the locations of at
16 least one, preferably a plurality, of hypothetical
17 shot-receiver pairs 42/44. The direction from the
18 hypothetical shot location 42 to the mid-point 40 is
19 taken to provide the starting angles for tracing the
20 path 46 of a ray propagating from the shot location
21 42. If shear wave conversion is used, this initial
22 direction is corrected using a first order
23 approximation. Typically, when the ray strikes the
24 first inter-layer boundary 104, the path 46 will
25 deviate from the notional path 48 between the shot
26 location 42 and the mid-point 40. The propagation
27 path 46 is calculated using ray tracing techniques
28 and the model parameters as described above, in
29 order to determine the reflection point 50 and the
30 emergence point 52 at which the ray exits from the
31 model. In general, the reflection point 50 will be
32 different from the mid-point 40 and the emergence

1 point 52 will be different from the initial
2 hypothetical receiver position 44. The deviation D1
3 between the initial mid-point 40 and the calculated
4 reflection point 50 may be calculated, as may the
5 deviation D2 between the initial receiver location
6 44 and the calculated emergence point 52. The
7 actual mid-point 54 between the hypothetical shot
8 location 42 and the emergence point 52 may also be
9 calculated. For the purposes of the present
10 embodiment of the invention, the emergence point 52
11 and the difference D3 between the calculated
12 reflection point 50 and the actual mid-point 54 are
13 stored. In addition, further attributes such as the
14 travel time and signal amplitudes may be calculated
15 and stored also.

16
17 If the emergence point 52 is not sufficiently close
18 to the initial hypothetical receiver position 44,
19 further iterations may be performed to obtain an
20 emergence point that is closer to the receiver
21 position. For every source/receiver pair 42/44 for
22 which the distance D3 between the desired mid-point
23 40 and the actual mid-point 54 is greater than a
24 predetermined threshold value, several iterations
25 may be performed until D3 is smaller than the
26 threshold value, or a maximum number of iterations
27 is reached. This iterative procedure selects a new
28 hypothetical receiver position 44 (and hence a new
29 mid-point 40 and therefore a new starting direction
30 from the hypothetical source 42 to the new mid-
31 point), based on the difference D3. Preferably, the
32 iterative algorithm is based on the weighted average

1 of previous iterations, and will generally converge
2 within three iterations.

3

4 In the preferred embodiment of the invention, the
5 survey area is initially divided into a relatively
6 coarse grid and the set of points selected as the
7 initial mid-points 40 for the hypothetical
8 source/receiver pairs 42/44 are the central points
9 of the blocks of the grid. Figure 4 illustrates a
10 3x3 grid. Typically, a 9x9 grid provides a suitable
11 starting grid. For each block of the grid, a
12 plurality of hypothetical source/receiver pairs
13 42a,b,c/44a,b,c are selected, centred on the mid-
14 point 40. The illustrated example arbitrarily shows
15 three equally spaced source/receiver pairs 45
16 degrees apart. The actual offsets (distances
17 between sources and receivers) and azimuths of the
18 selected source/receiver pairs will depend on the
19 user's prior knowledge of the intended survey
20 parameters. The number of source/receiver pairs
21 appropriate in a particular case will vary. In
22 general, three or four pairs will be adequate, or
23 about 10% of the anticipated data density in the
24 actual survey data.

25

26 For each source/receiver pair of each block of the
27 grid, the iterative process described above is
28 carried out to determine reflection points,
29 emergence points and deviations D3, together with
30 any travel time and amplitude data and/or other
31 attributes such as incidence angle etc.

32

1 Next, each block of the grid is sub-divided into
2 smaller blocks, suitably using a 3x3 sub-grid, as
3 shown in the top right block of Figure 4. The
4 procedure described above in relation to the
5 starting grid is then applied to each block of each
6 sub-grid. This procedure is repeated for successive
7 sub-divisions of each block until the deviations D3
8 become uniform (within predetermined tolerances)
9 between successive sub-divisions of a particular
10 block. At this point, it is assumed that further
11 iterations will not lead to any significant changes
12 in D3. Uniformity between successive values of D3
13 may be checked, for each offset/azimuth pair, by
14 comparing the maximum distance between the deviation
15 vectors for each sub-grid with a pre-defined
16 constant. Further, a minimum width for the sub-grid
17 blocks may be specified, so that the recursion stops
18 when the grid-elements reach that minimum value.

19

20 It is preferable for the grids to have an odd number
21 of blocks on each side, since this means that the
22 central mid-point of each block of each grid remains
23 constant and does not have to be re-calculated in
24 each successive sub-grid.

25

26 The output from this process provides a database of
27 representative source/receiver pairs and
28 corresponding reflection points (and other
29 attributes as required in a particular application),
30 refined to a level of detail that reflects the
31 complexity of the geological model. The database
32 constitutes an empirically derived transfer function

1 of the model. The database suitably has a tree
2 structure reflecting the recursive nature of the
3 process of sub-dividing the sampling grid.
4

5 Referring now to the ray matching process, the
6 database of the geological model is used to derive
7 approximate reflection points (and values of other
8 attributes if required) for each shot/receiver pair
9 in a set of actual survey data from the survey area
10 simulated by the model. This is accomplished using
11 some form of matching algorithm. There are a number
12 of possible ray matching methods, based on searching
13 the database for one or more hypothetical source
14 receiver pairs (and corresponding reflection
15 point(s)) and/or mid-points which provide the
16 closest match(es) to the actual source receiver pair
17 and/or mid-point and estimating the reflection point
18 etc. of the actual source receiver pair on the basis
19 thereof.
20

21 The preferred ray matching method is based on a two-
22 step interpolation algorithm. The first step
23 involves selecting a set of hypothetical
24 source/receiver pairs from the database which are
25 close to the actual source/receiver pair of interest
26 and analysing the relationships between the offsets
27 and azimuths of the selected source/receiver pairs
28 and the values of the attributes (e.g. the deviation
29 between the mid-point and reflection point, travel
30 time, amplitude, incidence angle, etc.) associated
31 therewith. The second step involves deriving
32 corresponding attribute values for the actual

1 source/receiver pair on the basis of this analysis.
2 The attribute values derived for the actual
3 source/receiver pair are thus obtained by
4 interpolation of the attribute values associated
5 with the selected hypothetical source/receiver
6 pairs.

7

8 In the particularly preferred embodiment, this two-
9 step algorithm is implemented as follows.

10

11 In the first step, for each actual source/receiver
12 pair, the hypothetical data for each of the four
13 blocks of the database grid closest to the mid-point
14 of the actual source/receiver pair is extracted from
15 the database. For each of these four blocks, a set
16 of interpolated curves is generated, based on the
17 offsets and azimuths (at least one azimuth per
18 offset) of the hypothetical source/receiver pairs.
19 That is, for each attribute the values of the
20 attribute are plotted against the associated offset
21 and an interpolated curve is calculated. If there
22 is more than one azimuth for each offset, there will
23 be an attribute/offset curve for each azimuth.
24 Accordingly, the four grid blocks yield four sets of
25 interpolated curves, each set comprising at least
26 one attribute/offset curve for each attribute.
27 Then, from each of the four sets of curves, a value
28 for each of the attributes can be extracted
29 corresponding to the offset and azimuth of the
30 actual source/receiver pair, yielding four sets of
31 interpolated attribute values (one set per grid
32 block).

1

2 Since the actual survey data will generally include
3 a large number of source/receiver pairs with mid-
4 points close to one another, these will all require
5 the same set of interpolated curves to be derived
6 from the database. Rather than searching the
7 database for every actual source/receiver pair, the
8 search and creation of interpolated curves need only
9 be done once per block of the grid.

10

11 In the second step, the four sets of interpolated
12 attribute values are spatially interpolated (e.g.
13 based on the distances from the mid-points of the
14 respective grid blocks to the mid-point of the
15 actual source/receiver pair) to obtain a final set
16 of attribute values for the actual source/receiver
17 pair.

18

19 That is, the attribute values for the actual
20 source/receiver pairs can be regarded as being
21 calculated on the basis of interpolating transfer
22 function data associated with a selected subset of
23 hypothetical source/receiver pairs.

24

25 The method as described above allows attributes such
26 as reflection points, travel times and amplitudes to
27 be easily estimated for each source/receiver pair in
28 a set of actual survey data. The computational
29 burden of ray tracing required to generate the
30 database from which these estimated values are
31 derived can be controlled and limited so as to be
32 much lower than that involved in conventional

1 methods of applying ray tracing to the actual survey
2 data.

3

4 The foregoing description of embodiments of the
5 invention relates particularly to land surface based
6 survey operations, employing two-dimensional arrays
7 of source/receiver pairs. The invention may also be
8 adapted for vertical seismic profiling operations in
9 which the sources or receivers are arranged in a
10 linear manner; e.g. along a cable in a borehole.
11 The invention may be similarly adapted for
12 underwater surveys; e.g. where receivers are placed
13 on cables at the ocean bottom. The invention may
14 also be adapted for anisotropic media. The
15 invention further lends itself to parallel
16 processing, which may be applied to the ray tracing
17 calculations, database generation, and database
18 searching.

19

20 The methods may be implemented by means of a
21 computer program or a suite of computer programs,
22 which may be encoded on any suitable data carrier
23 and which may be executed by means of any suitable
24 data processing system.

25

26 It will be understood that the invention is not
27 limited to the particular embodiments described
28 above. Improvements and modifications may be
29 incorporated without departing from the scope of the
30 invention.

1 Claims

2

3 1. A method of analysing seismic survey data,
4 comprising:

5 (a) obtaining a numerical model describing the
6 geology of a survey area;

7 (b) calculating a transfer function for said model
8 which defines at least one attribute value within
9 said survey area for a set of hypothetical shot
10 source locations and corresponding receiver
11 locations;

12 (c) comparing a set of actual survey data
13 comprising a plurality of source/receiver pairs with
14 said set of hypothetical source locations and
15 receiver locations, and estimating at least one
16 actual attribute value for each of said
17 source/receiver pairs on the basis of said
18 comparison.

19

20 2. A method as claimed in claim 1, wherein: the
21 step (b) includes:

22 (d) selecting a set of initial points within said
23 survey area and selecting at least one hypothetical
24 source location and a corresponding hypothetical
25 receiver location centred on each of said points;

26 (e) for each of said source locations, calculating
27 the path of a ray through said model originating at
28 said source location and having an initial direction
29 towards said initial point so as to determine a
30 reflection point and an emergence point for said
31 ray.

32

1 3. A method as claimed in claim 2, wherein the
2 step of calculating said transfer function further
3 includes:

4 (f) for each of said source locations, calculating
5 a distance D1 between said initial point and said
6 reflection point, a distance D2 between said
7 hypothetical receiver location and said emergence
8 point, a mid-point between said hypothetical shot
9 location and said emergence point, and a distance D3
10 between said mid-point and said initial point; and
11 (g) where said distance D2 exceeds a predetermined
12 minimum value, selecting a second hypothetical
13 receiver location on the basis of said distance D3
14 and repeating steps (e) and (f) for said second
15 hypothetical receiver location.

16

17 4. A method as claimed in claim 3, wherein:
18 (h) where a new value of D3 calculated in step (g)
19 remains greater than said predetermined minimum
20 value, the method includes performing further
21 iterations of step (g) in which further hypothetical
22 receiver locations are selected based on a weighted
23 average of the distance D3 obtained in previous
24 iterations until a value of distance D3 is obtained
25 which does not exceed said predetermined value.

26

27 5. A method as claimed in any of claims 2 to 4,
28 wherein the method further includes:
29 (i) dividing said survey area into a plurality of
30 first blocks, said initial points selected in step
31 (d) comprising central points of said first blocks.

32

1 6. A method as claimed in claim 5, wherein the
2 method further includes:

3 (j) sub-dividing each of said first blocks into a
4 plurality of second blocks, selecting a second set
5 of initial points comprising central points of said
6 second blocks, and repeating said steps (d) and (e)
7 for said second set of initial points.

8

9 7. A method as claimed in claim 6 when dependent
10 on claim 4, wherein the method further includes:

11 (k) repeating said steps (f) to (h) for said second
12 set of initial points.

13

14 8. A method as claimed in claim 7, wherein the
15 method further includes:

16 (l) successively sub-dividing each of said blocks
17 into further blocks and repeating steps (j) and (k)
18 for said further blocks until the difference between
19 values of distance D3 calculated for successive
20 blocks does not exceed a predetermined value.

21

22 9. A method as claimed in any preceding claim,
23 wherein said transfer function comprises a database
24 of hypothetical source locations, receiver locations
25 and corresponding values of at least one attribute.

26

27 10. A method as claimed in any preceding claim,
28 wherein said step (c) comprises:

29 (m) applying a matching algorithm to said actual
30 survey data and said set of hypothetical source
31 locations and receiver locations so as to select a
32 subset of said hypothetical source locations and

1 receiver locations and calculating at least one
2 estimated attribute value for each of said
3 source/receiver pairs, on the basis of transfer
4 function data associated with said subset of said
5 hypothetical source locations and receiver
6 locations.

7
8 11. A method as claimed in claim 10, wherein said
9 estimated attribute values are calculated by
10 interpolating transfer function data associated with
11 said subset of hypothetical source locations and
12 receiver locations.

13
14 12. A method as claimed in any preceding claim,
15 wherein said at least one attribute includes at
16 least one of: reflection point, deviation between
17 mid-point and reflection point, travel time,
18 amplitude and incidence angle.

19
20 13. A seismic survey method comprising obtaining a
21 set of seismic survey data for a survey area and
22 analysing said seismic survey data using a method as
23 claimed in any one of claims 1 to 12.

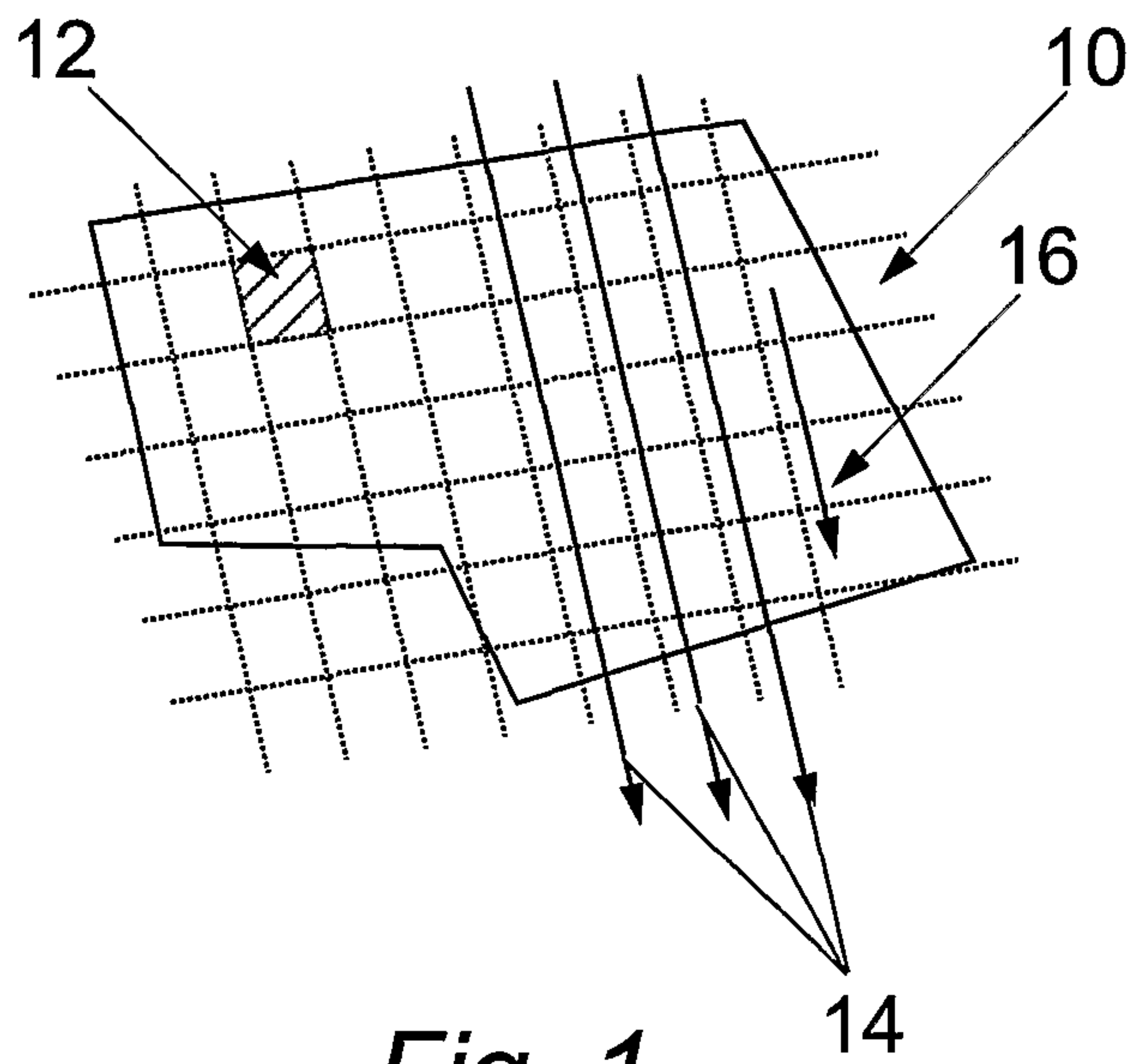
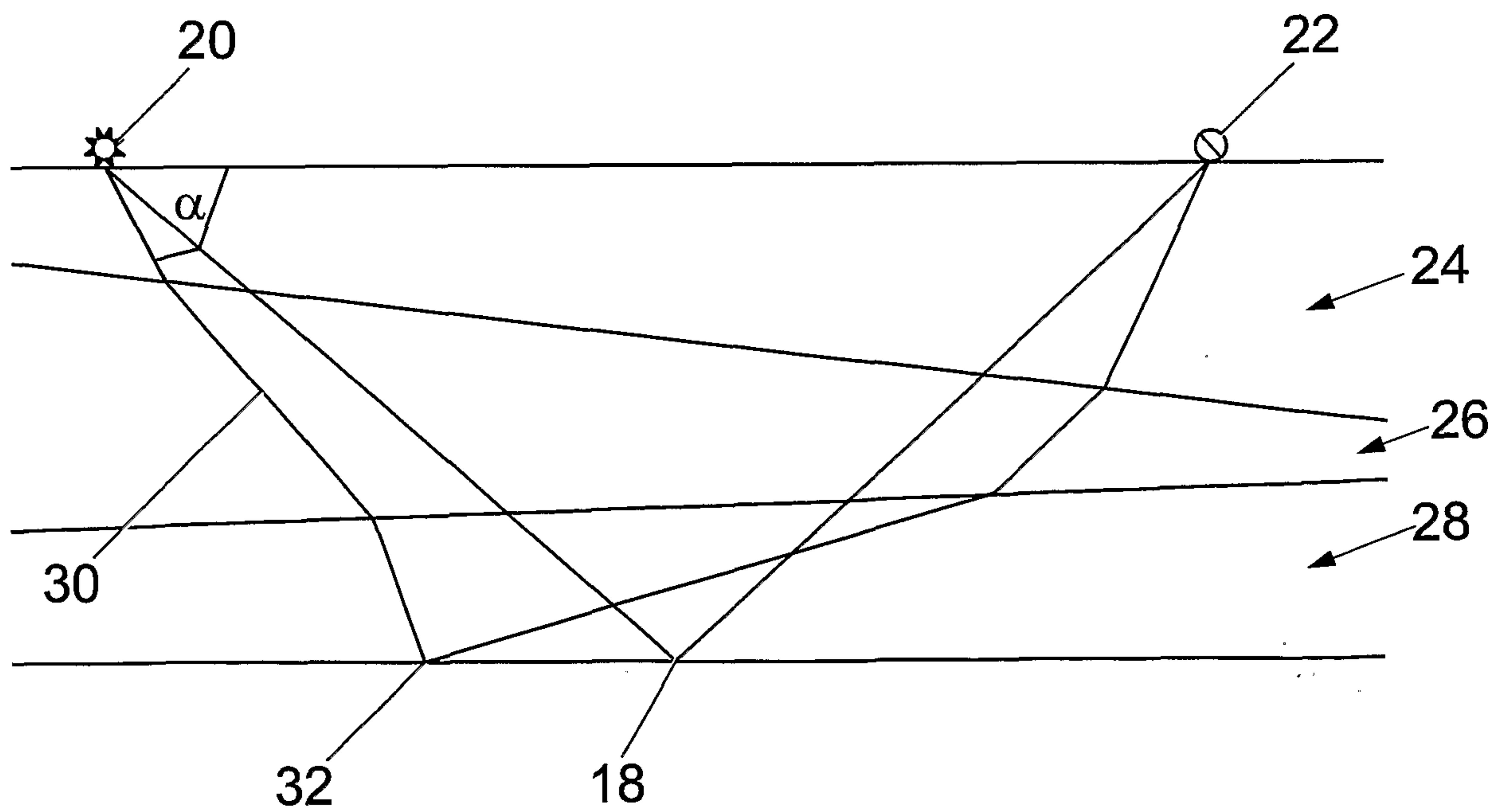
24
25 14. A computer program or a suite of computer
26 programs adapted to execute a method as claimed in
27 any one of claims 1 to 13.

28
29 15. A data processing system adapted to execute one
30 or more computer programs as claimed in claim 14.

31

- 1 16. A data carrier encoded with one or more
- 2 computer programs as claimed in claim 14.

1 / 2

*Fig. 1**Fig. 2*

2 / 2

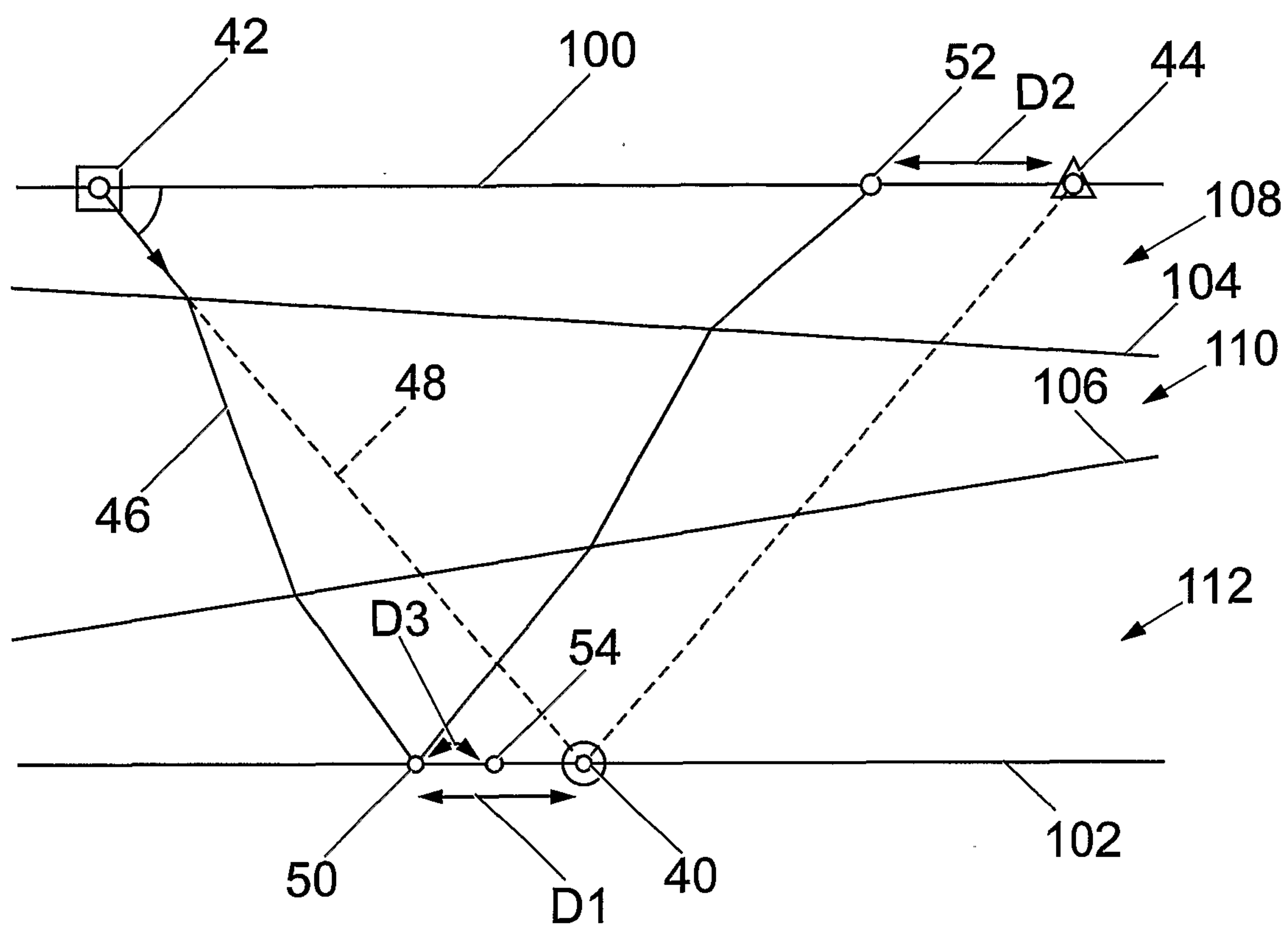


Fig. 3

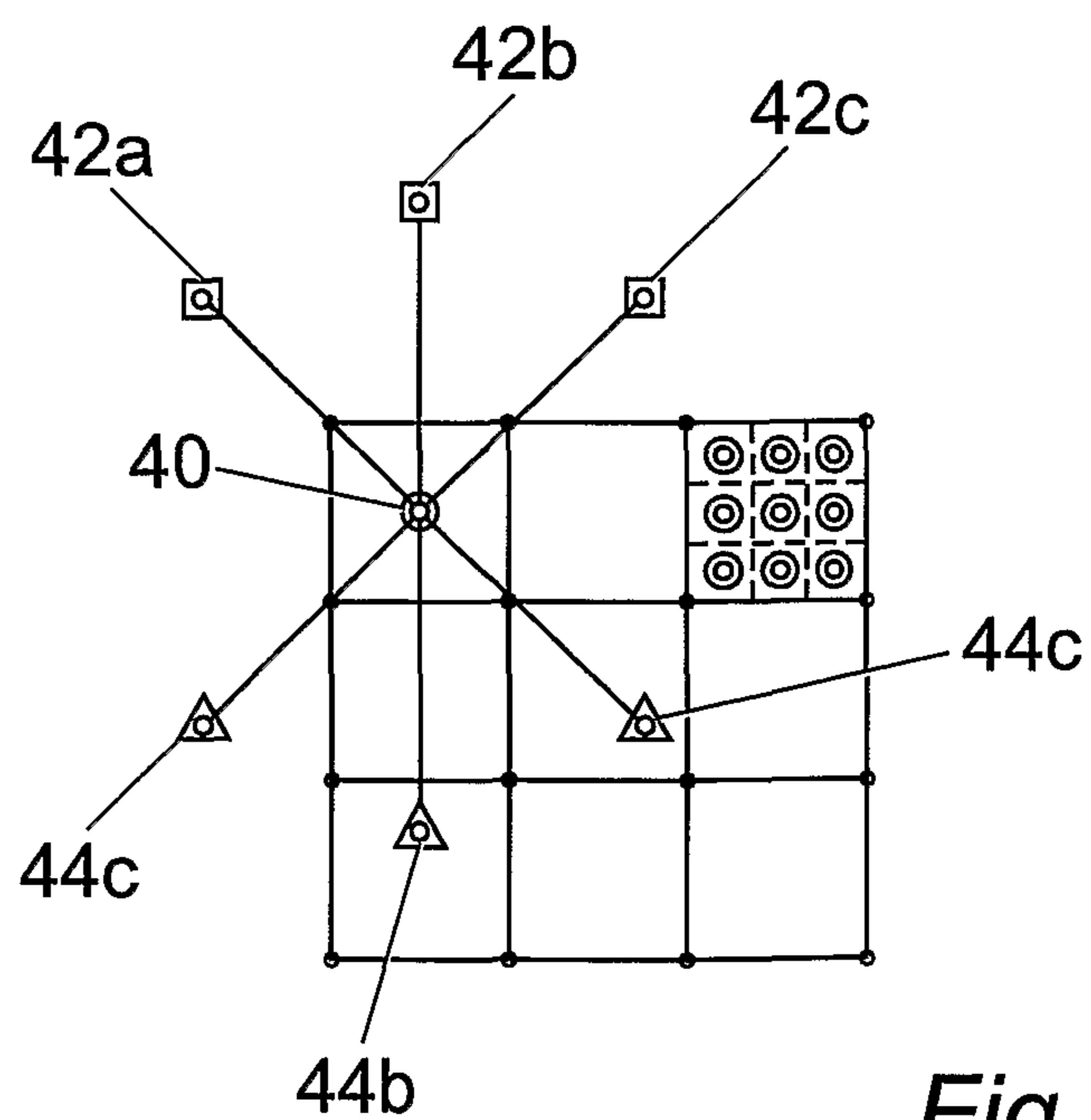


Fig. 4

