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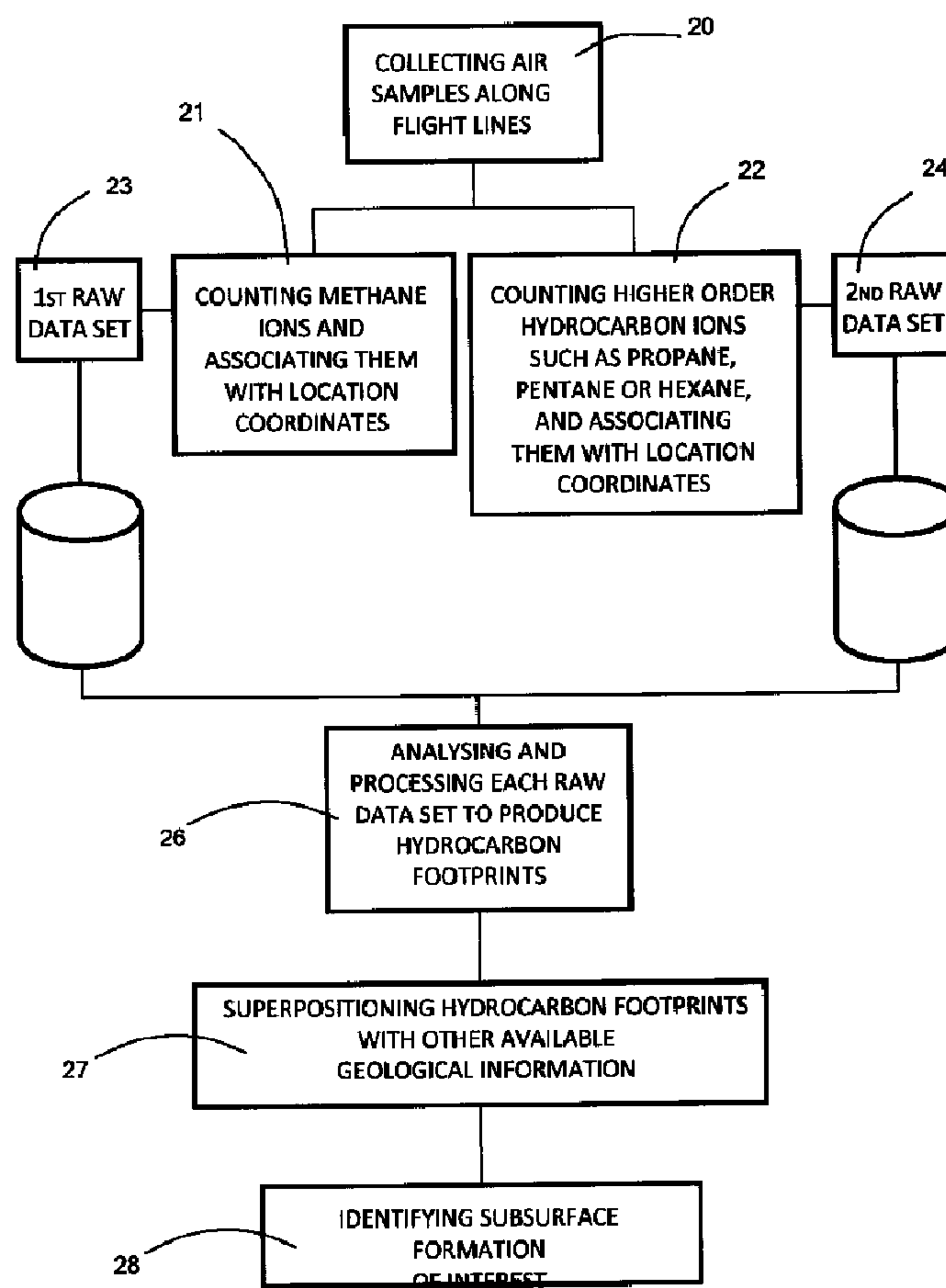
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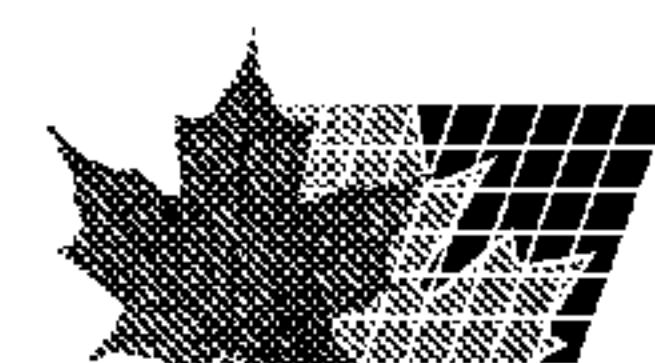
(54) Titre : METHODE ET APPAREIL POUR LA DETECTION DE DEPOTS D'HYDROCARBURES

(54) Title: METHOD AND APPARATUS FOR DETECTION OF HYDROCARBON DEPOSITS



(57) Abrégé/Abstract:

A method and apparatus is provided for detecting and categorizing subsurface hydrocarbon reservoirs. Air samples are collected and analyzed by counting hydrocarbon ions, such as methane ions and counting at least one higher order hydrocarbon ions, such



(57) **Abrégé(suite)/Abstract(continued):**

as propane, pentane or hexane. The methane ions and at least one higher order hydrocarbon ions are associated with location coordinates to form a first raw data set and second raw data set. The first and second raw data sets are analyzed and processed to produce hydrocarbon footprints. The hydrocarbon footprints are superpositioned with other available geological information and subsurface formations of interest are identified.

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ABSTRACT

2 A method and apparatus is provided for detecting and categorizing subsurface
3 hydrocarbon reservoirs. Air samples are collected and analyzed by counting
4 hydrocarbon ions, such as methane ions and counting at least one higher order
5 hydrocarbon ions, such as propane, pentane or hexane. The methane ions and
6 at least one higher order hydrocarbon ions are associated with location co-
7 ordinates to form a first raw data set and second raw data set. The first and
8 second raw data sets are analyzed and processed to produce hydrocarbon
9 footprints. The hydrocarbon footprints are superpositioned with other available
10 geological information and subsurface formations of interest are identified.

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1 **“METHOD AND APPARATUS FOR**
2 **DETECTION OF HYDROCARBON DEPOSITS”**
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4 **FIELD OF THE INVENTION**

5 This invention relates to apparatus and methodologies for detection
6 and characterization of hydrocarbon microseeps in the assessment of
7 hydrocarbon deposits. More particularly the invention relates to detection of
8 methane ions and higher order hydrocarbon ions and establishing hydrocarbon
9 intensity footprints representing hydrocarbon deposits for superposition over
10 geological features.

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12 **BACKGROUND OF THE INVENTION**

13 It is known to identify subsurface hydrocarbon reservoirs like
14 hydrocarbon reservoirs by the detection and analyzing of microseeps.
15 Microseeps are defined as leakage of hydrocarbons from subsurface reservoirs
16 to the surface and into the atmosphere. Various different methods are known for
17 detection and analysis of microseeps.

18 US Patent 4,338,029 to Macourt relates to a method of hydrocarbon
19 exploration wherein air samples are collected while traversing an area by aircraft.
20 Air samples are collected using an air intake, a focusing tube or an aerodyne
21 tube mounted on an aircraft. The air samples are subjected to spectroscopic
22 analysis to determine the extent of halogens and hydrocarbons present in the air
23 samples. The spectrometer is coupled to a navigating system so that the output
24 of the spectrometer can be correlated with the position of the aircraft over the
25 ground. Macourt provides an overall count of the hydrocarbons present in the

1 collected air samples but does not assist in the characterization of the results for
2 the identification of a commercially viable subsurface reservoir.

3 US Patent 7,542,850 to Humphrey et al. relates to methods for
4 processing geophysical survey data which is collected during aerial exploration of
5 hydrocarbon deposits or ore bodies. More particularly the invention relates to a
6 method for synchronizing data recorded from one or more sensors. The method
7 comprises receiving a first and second geophysical data from a first and second
8 sensor. The geophysical data collected by the two sensors are associated with
9 position and time data to get two sets of merged data. Further, errors can be
10 detected by comparing the merged data.

11 CA 2,636,180 to Breukelman et al. relates to method for locating
12 and differentiating areas with high shale content from areas of low shale content
13 using gravity gradient measurements. The gravity gradiometer instrument is
14 located in an aircraft which flies in a selected pattern over the terrain to be
15 surveyed and measures one or more components or combinations of
16 components of the gravitational gradient at a plurality of points on said terrain.
17 The measurements are recorded and analyzed to determine and mark deposits
18 large enough to exploit economically.

19 What is still required in the prior art is to be able to better detect and
20 characterize microseep information for the investigation and differentiation of
21 subsurface formations of interest from the predominant background level of
22 microseep data.

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SUMMARY OF THE INVENTION

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Herein, embodiments of the invention are directed to the detection of microseeps from subsurface formations/reservoirs and methods for distinguishing (categorization) subsurface formations or reservoirs of interest, being those most likely amenable to commercial exploitation. Further, embodiments of the apparatus and methodologies of the present invention enable determination whether the subsurface formation is a source of dry gas or oil (rich gas) and also to predict the potential of the subsurface formation for commercial exploitation.

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In embodiments of the invention, apparatus establishes the amount or intensity of methane, or, methane and an amount or intensity of at least one higher order hydrocarbon present in the collected air samples. Accordingly, one can establish the general nature of the subsurface formation. Further, the hydrocarbon and spatial data are combined to establish one or more sets of hydrocarbon intensity footprints of hydrocarbon deposits for alignment with and superposition over geological features. Hydrocarbon intensities can be associated with a geological map of the subsurface formations formed below the surveyed terrain so that one can readily determine the size, shape and orientation of the subsurface formations and whether the detected subsurface formations can potentially be exploited industrially.

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Accordingly in one broad aspect of the present invention a method of detecting and categorizing subsurface hydrocarbon reservoirs comprises traversing a plurality of flight lines over terrain to be surveyed for establishing a

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1 two-dimensional grid over the terrain which corresponds to the subsurface
2 formations therebelow. Air samples are collected along the flight lines.
3 Hydrocarbon ions present in the collected air samples for each of a plurality of
4 location co-ordinates along the flight lines are counted for establishing at least
5 one raw data set of the hydrocarbon ion count at each of the plurality of location
6 co-ordinates. The hydrocarbon ions counted are methane ions and/or at least
7 one higher order hydrocarbon ions. Amplitude anomalies from the at least one
8 raw data set are isolated for establishing at least a first residual data set of data
9 points. Each data point of the residual data set is indicative of the hydrocarbon
10 intensity at each of the plurality of location co-ordinates in the two-dimensional
11 grid. The at least first residual data set is mapped on the two-dimensional grid. A
12 first-threshold hydrocarbon intensity of interest is established. Data points
13 relatably adjacent one another within the two-dimensional grid and having
14 intensities equal to the first-threshold hydrocarbon intensity are identified. Such
15 equal-intensity data points are associated to form at least a first, first-threshold
16 footprint which encompasses the equal-intensity data points and any greater-
17 intensity data points having intensities greater than the first-threshold
18 hydrocarbon intensity. The at least a first, first-threshold footprint is superimposed
19 over a geological map of the subsurface formation within the terrain surveyed to
20 readily identify at least the location, size and shape of the terrain corresponding
21 to the subsurface formation of interest.

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23 Accordingly in another broad aspect of the present invention an
24 apparatus for detecting and categorizing hydrocarbon deposits in subsurface

1 formations comprises an aircraft with a scoop fitted thereon for traversing a
2 plurality of flight lines over terrain to be surveyed for establishing a two-
3 dimensional grid over the terrain which corresponds to the subsurface formations
4 therebelow. The scoop collects air samples and focuses the ions contained in the
5 air samples towards a detector array. The detector array comprises at least one
6 detector for counting hydrocarbon ions present in the collected air samples for
7 each of a plurality of location co-ordinates along the flight lines for establishing at
8 least one raw data set of the hydrocarbon ion count at each of the plurality of
9 location co-ordinates. The hydrocarbon ions counted are methane ions and/or at
10 least one higher order hydrocarbon ions. The apparatus further comprises at
11 least one processing unit for receiving and analyzing the at least one raw data set
12 for creating footprints of interest indicative of the hydrocarbon intensities
13 contained in the collected air samples and superimposing the footprints over a
14 geological map of the subsurface formation within the terrain surveyed to readily
15 identify at least the location, size and shape of the terrain corresponding to the
16 subsurface formation of interest.

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BRIEF DESCRIPTION OF THE DRAWINGS

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Fig. 1 is a block diagram of the microseep detection apparatus of the invention according to an embodiment of the invention;

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Fig. 2A, 2B and 2C are various views of the electromagnetic focusing tube according to an embodiment of the invention;

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Fig. 3 is a flowchart illustrating the method of the invention according to an embodiment of the invention;

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Fig. 4 is a section of the geological map of a subsurface formation which was within the area surveyed as an example of the invention;

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Fig. 5A is a section of the survey flight plan showing the flight lines according to an example of the invention;

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Fig. 5B is a representation of the flight lines with the methane and higher order hydrocarbon (propane is detected in the example) residual data sets mapped on each flight line according to an example of the invention;

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Figs. 6A through 6F are schematic representations of the steps involved in the analysis (isolation of residual amplitude anomalies) of the raw data set corresponding to the methane ions detected in the collected air samples for one flight line according to an example of the invention;

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Fig. 7A through 7F are schematic representations of the steps involved in the analysis (isolation of residual amplitude anomalies) of the raw data set corresponding to one of the higher order hydrocarbon ions detected (propane is detected in the example) in the collected air samples for one flight line according to an example of the invention;

1 Fig. 8A is a diagrammatic representation of propane footprints
2 created by associating equal-intensity data points of like propane intensities
3 according to an example of the invention;

4 Fig. 8B is an exploded view of one propane footprint of Fig. 8A;

5 Fig. 8C is a diagrammatic representation of those propane
6 footprints which fall above the threshold areal extent selected according to an
7 example of the invention. Fig. 8C is a subset of Fig. 8A along line AA;

8 Fig. 9A is a representation of the methane footprints associated
9 with the corresponding methane intensities and superimposed on the section of
10 the survey flight plan illustrated in Fig. 5A according to an example of the
11 invention;

12 Fig. 9B is a representation of the methane footprints superimposed
13 on the section of the geological map illustrated in Fig. 4 according to an example
14 of the invention;

15 Fig. 10A is a representation of the higher order hydrocarbon
16 footprints associated with the corresponding higher order hydrocarbon intensities
17 and superimposed (propane footprints are superimposed in the example) on the
18 section of the survey flight plan illustrated in Fig. 5A according to an example of
19 the invention;

20 Fig. 10B is a representation of the higher order hydrocarbon
21 footprints superimposed (propane footprints are superimposed in the example)
22 on the section of the geological map illustrated in Fig. 4 according to an example
23 of the invention;

1 Fig. 11A is a representation of the higher order hydrocarbon
2 footprints associated with the corresponding higher order hydrocarbon intensities
3 and superimposed (pentane footprints are superimposed in the example) on the
4 section of the survey flight plan illustrated in Fig. 5A according to another
5 example of the invention;

6 Fig. 11B is a representation of the higher order hydrocarbon
7 footprints superimposed (pentane footprints are superimposed in the example) on
8 the section of the geological map illustrated in Fig. 4 according to another
9 example of the invention;

10 Fig. 12 is a representation of the higher order hydrocarbon
11 footprints superimposed on another section of the geological map of the terrain
12 which was surveyed showing the general orientation of the footprints;

13 Fig. 13 is a representation of the legend associated with Figs. 9A to
14 11B; and

15 Fig. 14 is a representation where the commercially viable higher
16 hydrocarbon intensities (propane intensity profile) for one flight line is coupled
17 with the seismic data collected from a 3-D seismic survey of the geological area
18 where the commercially viable propane footprints are located according to an
19 example of the invention.

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1 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

2 According to an embodiment of the invention an aerial survey is
3 conducted by traversing a terrain potentially containing subsurface
4 formations/reservoirs of commercially exploitable hydrocarbon reserves. Survey
5 data is collected for indexing with the microseep data.

6 Having reference to Fig. 1, an aircraft (not shown) is fitted with a
7 microseep detection apparatus 1 comprising a scoop 2, a contaminant separator
8 3, a detector array 4, a navigation system 5 and at least one data processing unit
9 6 for processing and analyzing data. The data processing unit is located in the
10 aircraft or at a remote location.

11 The air scoop is positioned on the aircraft so as to minimize
12 contamination. For example, mounting of the scoop ahead of the aircraft engines
13 avoids exhaust, unburned fuel and other hydrocarbon contaminants. In the case
14 of a twin engine, low wing aircraft such as a Piper Navajo the scoop is located on
15 the top of the fuselage of the aircraft. In order to avoid air turbulence at the face
16 of the scoop the scoop is preferably positioned within the area of a smooth
17 slipstream such as the fuselage. Use of an aircraft with a rear-mounted engine
18 minimizes any concern for contamination.

19 With reference to Fig. 2, a form of scoop 2 is an electromagnetic
20 focusing tube 10. The tube 10 comprises a pyramidal scoop having converging
21 walls 11 and 12. Each wall is formed of overlapping louvers 13 for focusing the
22 charged ions of the air samples towards a collection tube 14 at downstream
23 apex, while permitting the majority of the air to be vented or discharged laterally
24 through the louvers 13. The louvers 12 are angled and overlapping so as form a

1 continuous and focused ion path, yet causing a tortuous path for venting of the air
2 and forming a concentrated air sample. The collection tube 14 is connected to the
3 detector array 4 of Fig. 1.

4 For removal of foreign particulates including dust and insects the
5 concentrated air sample can be directed through the separator 3. An example of
6 such a separator 3 is a centrifugal separator which uses centrifugal forces to trap
7 the particulate matter. A centrifugal separator comprises a coiled tube which
8 directs the air sample in a circular path and one or more tangential traps are
9 provided along the coiled tube to capture the particulates.

10 The concentrated air sample is transferred to the detector array 4
11 for detection of hydrocarbons.

12 According to an embodiment of the invention the detector array 4
13 detects at least two distinct bands (channels) of hydrocarbons contained in the air
14 samples. A first, direct current discharge spectral emission type detector (DCD)
15 detects the total number of hydrocarbon ions, the bulk of which are methane ions.
16 Suitable detectors for the higher order hydrocarbon bands can include one or
17 more second sensors such as photoionization detectors (PID). Further, other
18 detectors can be added for carbon dioxide, iodine, or any other indicative
19 component. Such detectors may be a DCD or a PID or other forms of detectors.

20 Measurements of the monitored hydrocarbon levels by each
21 detector are qualitative in nature, rather than quantitative, in that the actual
22 concentration of hydrocarbons in each band is not directly determinable. A
23 resultant spectrum of hydrocarbons is arrived at by further analysis of the

1 hydrocarbon levels measured. The resultant spectrum is indicative of microseeps
2 emanating from subsurface pressurized oil or gas reservoirs.

3 The first detector (DCD) monitors total hydrocarbon ions (a first
4 channel or band) ranging from the lightest compound, methane (C1), to the more
5 complex (higher order) hydrocarbon chains such as ethane (C2), propane (C3),
6 butane (C4), pentane (C5), and heavier hydrocarbons. Because of the
7 overwhelmingly large concentrations of methane compared to the ever-
8 decreasing relative concentrations of the heavier hydrocarbons in a given air
9 sample, this first detector is substantially a methane, or dry gas detector. As
10 such, methane gas reservoirs can be isolated in the microseep mapping process
11 from oil reservoirs and potentially from "wet" gas or liquids-rich gas reservoirs.
12 The oil and rich gas reservoirs will also have associated methane microseeps
13 emanating therefrom because methane is ever-present in oil and rich gas pools.

14 Applicant believes that the corollary is not necessarily true. In the
15 case of dry gas or pure methane gas pools sourced from biogenic environments,
16 the methane is a byproduct of bacterial interaction and decay of organic matter
17 which is not thermogenically derived. The biogenic methane gas produced is not
18 the result of a combined high overburden pressure and high temperature source
19 environment. Swamp or bog gas, animal feedlot and landfill/garbage dump gas
20 is also pure methane with a biogenic source. Therefore, if a methane microseep
21 footprint is known to be biogenic in nature, this provides evidence that any
22 coincident oil (rich gas) footprint likely originates from a different subsurface
23 source.

1 Applicant understands that coal bed methane, or coal seam gas,
2 may be dry (pure) methane, but some coal seams are actually the source beds
3 for thermally generated complex hydrocarbons. Much of the large but shallow
4 gas reserves in the Upper Cretaceous stratigraphic sequences in North America
5 are of a biogenic origin, and therefore it is convenient and useful to be able to
6 detect, measure and ultimately map these dry gas reservoirs as potential
7 exploration targets. Because the composition of biogenic gas is pure methane,
8 the gas exhibits the lowest heating/energy value of all the hydrocarbon
9 compounds. Biogenic methane is considered to be "immature" gas. A second
10 important source of pure methane, or dry gas, comes from "over-mature"
11 environments where the geological thermal regime has gotten progressively more
12 intense, post-hydrocarbon generation, from a combined pressure and
13 temperature perspective. The oil and gas originally expelled from source rocks
14 becomes thermally degraded as the volatile hydrocarbons are driven off by
15 "cooking" the mature petroleum into an over-mature state, that results in all
16 hydrocarbons other than methane being expelled from the reservoir, with dry gas
17 (methane) being the only remaining hydrocarbon left to produce microseeps into
18 the atmosphere. The first "total hydrocarbon" detector detects this over-mature
19 methane. "Cooked" gas reservoirs exist in geological basins worldwide, and are
20 usually associated with deep, high pressure settings in compressional regimes.
21 Both sandstone and carbonate reservoirs can house "cooked" methane gas
22 pools, but the Devonian reefal carbonates of west-central Alberta can have gas
23 reservoirs containing only methane and hydrogen sulphide (H₂S) in various
24 proportions.

1 A third class of dry methane exists in the form of frozen gas
2 hydrates normally found in deep offshore continental shelf environments. These
3 potentially commercial methane gas pockets are the subject of many large
4 research projects being conducted internationally. Like permafrost, hydrates are
5 made up of methane in association with ice crystals. Dry gas microseep mapping
6 of gas hydrates may hold significant promise for the future exploration for new
7 unconventional methane gas reserves in the future.

8 The one or more second detectors (PID) monitor a second channel
9 of higher order hydrocarbon ions including propane (C3) and heavier
10 hydrocarbons such as butane (C4), pentane (C5), hexane (C6) and heavier. It is
11 important to note that methane (C1) and ethane (C2) are not substantially
12 detected along with the heavier hydrocarbon bands, therefore the heavier
13 hydrocarbon suites preclude any significant "dry" gas (methane) readings. The
14 one or more second detectors measure the concentration of C3 and heavier
15 hydrocarbons, including condensate, which is a prevalent component I liquids-
16 rich natural gas streams. This results in biogenic and "cooked" natural gas
17 content being effectively invisible to this detector, and by process of elimination,
18 all monitored hydrocarbons must be in the liquids-rich gas or oil window. By
19 definition, all of these hydrocarbons must have been thermally generated within
20 kitchen-based source beds within one or more petroleum systems of a mature
21 sedimentary basin.

22 A third detector of the one or more second detectors, a higher order
23 hydrocarbon detector (PID), can be directed for sensing a third channel of
24 heavier components of any higher order hydrocarbons including pentane (C5),

1 also known as condensate, and heavier, more complex hydrocarbons. This third
2 channel of microseep information is used in collaboration with the second
3 channel of the second detector which measures concentrations of propane (C3)
4 and heavier. Because pentane is heavier than propane it is expected that
5 propane ion counts in a given microseep sample would exceed the pentane ions
6 counts in the same sample. Therefore, there is a tendency to bias the propane
7 and heavier (C3+) spectrum slightly over the pentane and heavier (C5+)
8 readings. The combination of both these second and third channels gives
9 stronger evidence of hydrocarbon accumulation than viewing either one of these
10 channels in isolation.

11

12 Collection of air samples, analysis of data and superposition

13 With reference to Fig. 3 a method of detecting and categorizing
14 subsurface hydrocarbon reservoirs comprises collecting air samples (block 20),
15 counting hydrocarbon ions, such as methane ions (block 21) and counting at
16 least one higher order hydrocarbon ions, such as propane, pentane or hexane
17 (block 22). The methane ions and at least one higher order hydrocarbon ions are
18 associated with location co-ordinates to form a first raw data set and second raw
19 data set (Figs. 6A, 7A and blocks 23 and 24). The first and second raw data sets
20 are analyzed and processed to produce hydrocarbon footprints (block 26). The
21 hydrocarbon footprints are superpositioned with other available geological
22 information (block 27) and subsurface formations of interest are identified (block
23 28).

1 With reference to Figs. 5A and 5B an aircraft 15 is fitted with the
2 scoop 2 is flown (traversed) over the terrain to be surveyed along flight lines. The
3 flight lines marked 30 establish a two-dimensional grid marked 31 over the terrain
4 to be surveyed. Along a given flight line, discrete "snapshot" samples (microseep
5 readings) are digitally recorded once per second (sample point). Given a
6 groundspeed of the aircraft of 288 km/hr, this sampling frequency equates to 80
7 meter spacing between sample points along the flight lines. The spacing between
8 two adjacent flight lines is in the range of about 0.5 kilometer to about 1
9 kilometer. Preferably, the maximum spacing between two adjacent flight lines is 1
10 kilometer, although decreasing the spacing between adjacent flight lines reduces
11 aliasing and increases the reliability of the gridded data surface when the data is
12 mapped.

13 The total number of hydrocarbon ions detected in the collected air
14 samples for each snapshot along a flight line by the first detector (DCD) (which
15 are essentially methane ions) is associated with location co-ordinates to form a
16 first raw data set 100 (Fig. 6A). The higher order hydrocarbon ions detected in
17 the collected air samples by the second detector (PID) for each snapshot along a
18 flight line is associated with location co-ordinates to form a second raw data set
19 200 (Fig. 7A).

20 Figs. 6A through 6F illustrate the various steps involved in the
21 analysis of the first raw data set relating to methane ions. Figs. 7A through 7F
22 illustrate the various steps involved in the analysis of second raw data relating to
23 the heavier (higher order) hydrocarbon ions detected.

1 Each microseep reading (snapshot) is referred to as a fiducial. With
2 reference to Figs. 6B and 7B, the start fiducial of each of the first and second raw
3 data sets for each flight line is shifted by a specified lag. The need to shift the
4 fiducial is due to the physical transit time from receipt of the air sample entering
5 the scoop to receipt of the air sample at the detector array where the
6 hydrocarbon ions are detected and recorded along with the positional
7 information. The actual position of the microseep column is where the air sample
8 enters the scoop as opposed to where the hydrocarbon ions are recorded. The
9 lag time is the time taken for the hydrocarbon ions to travel from the scoop to
10 where the hydrocarbon ions are recorded.

11 With reference to Figs. 6B and 7B, first and second resampled data
12 sets 101 and 201, respectively are generated. The first and second raw data sets
13 100, 200 are resampled to account for the variable ground speed of the aircraft.
14 Resampling of data is required after a lag correction. Resampling of data is done
15 in order to convert the entire dataset from a constant sampling frequency in the
16 time domain to a constant sampling frequency in the spatial domain. Resampling
17 is also needed to mitigate aliasing effects when the data is mapped. The
18 sampling rate at the detector is a constant one second in the time domain, but the
19 distance on the ground that the aircraft travels in one second will differ depending
20 on whether the aircraft is flying into a headwind or with a tailwind. Given a
21 constant wind speed and a constant airspeed, the ground speed of the aircraft
22 will be greater when flying with a tailwind than when flying into a headwind. In
23 such a case, the true ground speed will be an average of the two groundspeeds
24 since the tailwind increases the groundspeed of the aircraft by the same amount

1 that the headwind slows down the groundspeed. If the average groundspeed of
2 the aircraft is 80 meters per second, the data can be resampled to a frequency of
3 80 m/s in the time domain. The resampling rate (frequency) is not restricted to the
4 average groundspeed of the aircraft. However, one way of calculating the
5 resampling rate is by taking the average speed of the aircraft over several flight
6 lines flown in opposite directions.

7 With reference to Figs. 6C and 7C, the first and second resampled
8 data sets 101, 201 are passed through one or more filters to remove noise and
9 result in a first smoothed data set 102 (Fig. 6C) and second smoothed data set
10 202 (Fig.7C) . This is done by removing unwanted high amplitude and/or short
11 wavelength data that display characteristics common to noise. This is achieved
12 by convolving the original signal with any number or combination of linear or non-
13 linear filters which may include low-pass, band-pass, weighted or simple
14 averaging filters.

15 In choosing a suitable noise reduction method, the power spectra of
16 Fourier transformed noise reduced signals and original signals can be looked at
17 to help identify noise.

18 One way of achieving noise reduction is by convolving the data first
19 with a weighted average convolution filter. As a second step, the data may be
20 filtered again with an additional filter, such as a lowpass filter if further noise
21 reduction is warranted.

22 The entire procedure of noise reduction is described as follows: A
23 weighted averaging convolution filter is used alone or in combination with any

1 lowpass or other standard filtering technique. A suitable weighted averaging filter
 2 is a 5 element weighted average convolution filter as given below:

3 0.056293459, 0.173396061, 0.540620958, 0.173396061, 0.056293459

4 The filter is based on a normal distribution with a standard deviation
 5 of 0.25. The five elements of the convolution filter are weighted corresponding to
 6 the normal probability density function which is given by the formula,

7
$$\text{PDF} = 1/(S \cdot \sqrt{2 \cdot \text{PI}}) * \exp [- ((X-U)^2)/(2 \cdot S^2)]$$

8 where S is the standard deviation

9 U is the mean

10 X is the point at which the probability is to be calculated

11 PDF is the probability density function for the variable X

12 $\text{PI} = 3.1415$

13 The probability density function equation for the normal distribution
 14 can be found in any reference known to the skilled person. A value of 0.25 for the
 15 standard deviation was chosen such that the resulting bell curve was sufficiently
 16 smooth yet still provided enough of a peak of distribution.

17 The five elements of the filter correspond to Z factors of 0, +/-0.5,
 18 and +/-1.0, where the Z factor is equal to the number of standard deviations from
 19 the peak of the distribution to where X lies. The variable X is related to the value
 20 of Z by the formula, $X = Z \cdot S + U$. After the PDF values for each value of X was
 21 found, the cubed power of the PDF values were normalized so that the resulting
 22 5 elements of the filter added up to 1.0.

23 After the above filter is applied to the smoothed data sets 102, 202,
 24 the smoothed data sets can be further smoothed by applying an additional

1 lowpass filter to the data and then taking a weighted average of the outputs of the
2 lowpass filter and the above Normal Distribution filter.

3 It should be understood that other methods of noise identification
4 and removal or reduction may also be used. The Normal Distribution Filter
5 described is only one example.

6 With reference to Figs. 6D and 7D, a computer generated baseline
7 103, 203 is created for each of the two smoothed data sets 102, 202, respectively
8 . This is done so as to locate and isolate residual amplitude anomalies. In the art
9 of seismic analysis, and with reference to the Schlumberger Oilfield Glossary
10 (www.glossary.oilfield.slb.com), the term "amplitude anomalies" is an abrupt
11 increase in seismic amplitude that can indicate the presence of hydrocarbons,
12 although such anomalies can also result from processing problems, geometric or
13 velocity focusing or changes in lithology. Such amplitude anomalies can result
14 from changes in acoustic impedance, such as when a gas sand underlies a
15 shale.

16 Herein, in the context of microseep, the computer generated
17 baseline 103, 203 consists of a series of vertices 104, 204 (which separate
18 individual amplitude anomalies in the residual data sets) connected by straight
19 line segments 105, 205 so that vertices 104, 204 may be deleted or added in
20 order to refine the baseline 103, 203 in a subsequent manual baselining step. In
21 its simplest form, baselining can consist of applying low order trend lines or other
22 curves to the data. To generate a baseline, the baselining algorithm makes use
23 of non-linear and linear filtering techniques in addition to other convolution filters
24 that may shift the data either backwards or forwards by a given number of

1 fiducials, take arithmetic and/or weighted averages, wavelet analysis of the data,
 2 including Fourier transforms, application of trend lines to the data, or other known
 3 techniques in order to pick local minima that are to be used as vertices for the
 4 computer generated baseline.

5 A baselining algorithm for example begins with running a lowpass
 6 filter of 30 fiducials on the original (smoothed and noise reduced) signal, which
 7 will be referred to as "ORI". The resulting waveform (signal) after running the
 8 lowpass filter on the original data set is denoted by "LP". An algorithm to find the
 9 local minima of a signal is applied to both the "LP" and "ORI" signals, giving
 10 "LPMIN" and "ORIMIN", respectively. "LPMIN" and "ORIMIN" are not continuous
 11 signals; "LPMIN" and "ORIMIN" are defined only where a local minimum on "LP"
 12 or "ORI" occur, everywhere else the value of signal is undefined (i.e. they have
 13 no value). For each instance where "LPMIN" is defined (i.e. has a value) the
 14 nearest occurrence where "ORIMIN" is defined is used as a vertex in "BASE1",
 15 which is the first iteration of the computer generated baseline. A copy of "BASE1"
 16 is created and will be referred to as "BASE2". Each occurrence of "BASE1" is
 17 checked against the value of "ORI" at that same position (for the purposes of this
 18 explanation, this position will be referred to as fiducial#1). If the value of "BASE1"
 19 is greater than the value of "ORI" at fiducial#1, and there are no more instances
 20 of "BASE1" within 10 fiducials of fiducial#1, then "BASE2" is set to the value of
 21 "ORI" at fiducial#1. After every instance of "BASE1" has been checked against
 22 "ORI", "BASE2" is now the second iteration of the computer generated baseline.
 23 A copy of "BASE2" is created and will be referred to as "BASE3". Next, a rolling
 24 median with a moving window of 30 fiducials is applied to "ORIMIN" and the

1 result put into "MED1". "BASE2" is subtracted from "MED1" to give "MED2". A
2 constant variable, "TOL", is set to be equal to the value of the standard deviation
3 of "MED2" multiplied by 1.2 added to the mean of "MED2". If "BASE3", at the n^{th}
4 fiducial is greater than the value of "TOL", then "BASE3" at the n^{th} fiducial is set to
5 "BASE2" at the n^{th} fiducial plus an offset, where the offset is equal to "MED1" at
6 the n^{th} fiducial minus one third of the value of "MED2" at the n^{th} fiducial. "BASE3"
7 is now the third iteration for the computer generated baseline. Further iterations
8 for the computer generated baseline may be created through additional filtering
9 techniques but for the purposes of this explanation here, which is intended to
10 illustrate a general process for creating the computer generated baseline, only
11 three iteration of the baseline will be discussed. If it is determined that "BASE3" is
12 to be used as the computer generated baseline, a copy of "BASE3" is created
13 and will be denoted as "BASE4". "BASE4" is now interpolated between its
14 vertices (so "BASE4" is now continuous over the entire length of the flight line
15 and is subtracted from "ORI". The result of subtracting "BASE4" from "ORI" is the
16 residual signal (residual data set) which shows the presence or the absence of an
17 amplitude anomaly between any two baseline vertices.

18 It should be understood that other algorithms for baselining may
19 also be used. The algorithm described above is only one example and is the
20 algorithm currently used to generate the computer generated baseline 103, 203.

21 With reference to Figs. 6E and 7E, the baseline 103, 203 for each
22 of the two smoothed data sets 102, 202 can be further refined as a refined
23 baseline 103r or 203r by identifying baseline vertices which were not utilized or
24 detected in the above steps. If, between two baseline vertices 104, 204 which

1 may or may not be consecutive vertices, several local minima 106, 206 can be
2 identified on the signal and if a low order curve 107, 207 (e.g. polynomial, trend
3 line, or least squares) can be visually drawn through the local minima between
4 the two vertices 104, 204 in question, then this provides reasonably strong
5 evidence that additional vertices should be added and/or existing vertices should
6 be deleted. The low order curve 107 may take the form of a straight or near
7 straight trend line, a gently undulating polynomial, or a curve that that often
8 follows a shape similar to either an exponential decay curve or an exponential
9 growth curve. An example of a curve that has a shape similar to an exponential
10 growth/decay curve is that of a gamma distribution curve. The gamma distribution
11 has a general shape that increases rapidly at the start and then gently tails off.
12 Even if no local minima within an apparent amplitude anomaly as described
13 above can be seen or visually connected by any type of curve, the refined
14 baseline 103r, 203r can still be brought up into an amplitude anomaly in order to
15 visually equalize the amplitude anomaly with the rest of the flight line so that no
16 one amplitude anomaly is so intense that it overpowers the rest of the residual
17 signal.

18 With reference to Figs. 6F and 7F, the refined baselines 103r, 203r
19 are subtracted from the corresponding smoothed data sets 102, 102 to arrive at a
20 first and a second residual data set 109, 209. The first residual data set 109
21 comprises residual amplitude anomalies indicative of total hydrocarbon intensities
22 and is formed of a plurality of first data points (109i-109n). As the total
23 hydrocarbon intensities are substantially methane, each data point of the first
24 residual data set 109i is indicative of the methane intensity for each location co-

1 ordinate (snapshot) along a flight line. The second residual data set 209
2 comprises residual amplitude anomalies indicative of hydrocarbon intensities
3 from the at least one higher order hydrocarbon raw data set and is formed of a
4 plurality of second data points (209i-209n). Each of the second data points 209i is
5 indicative of the at least one higher order hydrocarbon intensity for each location
6 co-ordinate (snapshot) along a flight line.

7 If no refinement to the computer generated baseline is required, the
8 residual data set for each raw data set which is indicative of the hydrocarbon
9 intensity contained in the air samples collected for each flight line is arrived at by
10 subtracting the computer generated baselines from the corresponding filtered raw
11 data sets.

12 The residual data sets 109, 209 are normalized or averaged so that
13 extremely intense readings do not overpower and drown out the less intense
14 readings. One method to normalize the data is to apply a multiplying factor to
15 each flight line such that the arithmetic mean (or some other statistical quantity)
16 becomes the same for all flight lines. The flight line has to be of sufficient length
17 in order for this method of normalization to be used. If the flight line is not of
18 sufficient length then another method of normalization can be used.

19 With reference to Fig. 8A, the data points (equal-intensity data
20 points) of substantially equal magnitudes are joined to form a series (a first, first-
21 threshold footprint and subsequent first-threshold footprint) of footprints 300.

22 With reference to Fig. 5B, the residual data sets 109, 209
23 established for all the flight lines, are mapped on the two-dimensional grid 31

1 formed by the flight lines 30 to show the areal distribution and intensity of the
2 microseep signal over the entire survey area.

3 The residual data along a flight line 30a is substantially continuous.
4 The data between adjacent flight lines 30a, 30b is discontinuous. The flight lines
5 form a discontinuous two-dimensional grid 31, each flight line being associated
6 with at least the first residual data set. A data grid or surface 301 is created by
7 forming a more or less continuous data grid such as through a numerical
8 interpolation of the residual data set between discontinuous and adjacent flight
9 lines.

10 The data surface is created with a sufficiently small cell size in order
11 to honor the high frequency data of the residual data sets 109, 209 but at a large
12 enough cell size to mitigate aliasing effects. Any high frequency data and aliasing
13 effects in the data surface that remain can be smoothed for esthetic purposes by
14 either increasing the cell size or applying a smoothing filter to either the resulting
15 data surface or the original raw data.

16 Gridding or data surface formation is performed with a small
17 enough cell size to honor the high frequency data points in the residual data sets
18 and a smoothing filter is used to smooth the grid to a satisfactory degree.

19 For example, a smoothing filter can be used such as one that
20 drapes a Gaussian surface over a 5 cell by 5 cell window centered on a given cell
21 and replaces the centre cell by the sum of all 25 cells multiplied by their
22 corresponding filter element. It should be understood that other smoothing filters
23 may also be used to achieve the desired degree of smoothing.

1 The gridded data surface can be displayed with a color transform
2 and overlain on any available geological maps.

3 In order to identify data within the residual data set 109, 209 or
4 gridded data surface which are deemed to be insignificant, one can establish iso-
5 intensity functions (threshold values) on the data surface to form the footprints
6 300. The footprints 300 enclose areas of equal and higher intensity data points.

7 A "footprint" 300 is defined here as that portion of a given amplitude
8 anomaly that is above a certain first-threshold hydrocarbon intensity of interest.
9 As shown in Fig. 13, a first threshold can be commonly used is the 75th percentile
10 (upper quartile or top 25%), which means that microseep footprints are by
11 definition within the high range of all microseep intensities. Even greater
12 distinction can be set forth by determining residual data which is within higher-
13 threshold hydrocarbon intensity such as second-threshold hydrocarbon intensity
14 (say within a top 15%) or a third-threshold (within a top 10%) or a fourth-threshold
15 intensity (within a top 5%). A first-threshold footprint, second-threshold footprint
16 and higher-threshold footprints, resulting from the first, second and higher-
17 threshold hydrocarbon intensities, form a stacked footprint for further illustrating
18 the potential of the subsurface formation beneath the footprint.

19 With reference to Fig. 8B, a footprint is created by first identifying
20 data points, relatably adjacent one another within the data surface and having
21 intensities M1, M2, magnitude of which are equal to a selected threshold value of
22 interest (M1-a first-threshold value and M2- a second-threshold value) and
23 associating such data points to create a footprint 300. The footprint 300 is
24 indicative of the location, size, shape and orientation of the subsurface formation.

1 The gridded data surface, residual data sets 109, 209 and footprints
2 300 may also be checked for the general consistency of the amplitude anomalies
3 over a large area. No single anomaly should be so intense that it overpowers the
4 other anomalies in the area. Footprints 300 should not be oriented parallel or
5 near parallel to a flight line or have unusually sharp or pointed edges to them.
6 Such amplitude anomalies should be re-examined (i.e. the residual data sets
7 should be checked) to see if the baseline contains an incorrect vertex and if so,
8 the baseline should be modified.

9 Successive flight lines 30 are also inspected for any potential line-
10 by-line correlation. If it can be determined that adding or deleting one or more
11 baseline vertices 104 may give better line by line correlation, then this can be
12 taken as evidence the baseline 103 should be adjusted.

13 Comparing Figs. 8A and 8C, insignificant footprints 302 can be
14 further identified and separated by establishing an areal-extent threshold. For
15 example, an areal-extent threshold established could be 2 square kilometers.
16 Only those footprints 300 equal or greater than the established areal-extent
17 threshold (greater than 2 square kilometers) would be would be overlain on the
18 geological map. Fig. 8C shows only those footprints 300 which are greater than 2
19 square kilometers. Footprints 302 in Fig. 8A are not shown in Fig. 8C as these
20 footprints are less than 2 square kilometers. Any other criteria for separation
21 other than areal extent can be applied.

22 Applicant notes that the spatial patterns of microseep footprints
23 often provide evidence of the migration paths of hydrocarbons moving updip from
24 the deep kitchen areas of the basin, into either structural closures, or into

1 stratigraphic trapping conditions where further migration of oil or gas is halted by
2 changes in the geological facies, such as a porous and permeable reservoir rock
3 being in contact with laterally updip, low permeability lithology which terminates
4 the further movement of hydrocarbons; thus creating a stratigraphic oil or gas
5 pool without any four-way dip structural closure. These types of oil and gas pools
6 are often very difficult to image or resolve with two-dimensional (2-D) seismic
7 mapping. If the microseep footprint is sufficiently large in areal extent, suggesting
8 possible commercial viability, a three-dimensional (3-D) seismic survey could be
9 undertaken and centered over the microseep footprint. Knowing where the
10 trapped pool is located in plan view allows detailed scrutiny of the 3-D seismic
11 dataset to accurately predict the geological zone of interest, as well as its
12 approximate depth. If a successful oil or gas well was located and drilled within
13 the footprint, then the newly discovered pool or field could be the benchmark
14 example of a new exploration play-type in that particular sedimentary basin.
15 Because the microseep surveys are often large in areal extent, a trend or series
16 of similar footprints may also be considered to be prospective. A trend line can be
17 drawn along the footprints to indicate possible migration pathways, barriers to
18 migration or other lithological or geological trends. Fig. 12 illustrates trend lines
19 303 drawn along footprints superimposed on the geological map of the
20 subsurface formation. Trend lines need not be straight lines. A meandering trend
21 line indicates meandering channel facies or a migration pathway that does not
22 follow a straight or nearly straight line. If the newly discovered oil or gas pool
23 happens to fall within a microseep footprint which appears to be associated with
24 a series of similar undrilled microseep anomalies, it would be reasonable to

1 assume that additional latent petroleum and natural gas pools could be found by
2 expanding the scope of 3-D seismic coverage over the microseep footprint
3 “trend” with a reasonable expectation that more new pools may be discovered in
4 the same geological horizon as the first discovery. The additional 3-D seismic
5 data would again be coupled with footprints in future drill site selection. Neither
6 the microseep footprints nor the seismic dataset are sufficient, in isolation, to
7 locate the trap with certainty, but both independent information layers combined
8 can greatly improve the drilling success rate. Fig. 14 illustrates the coupling of
9 commercially viable methane residual data (109 or 209) with seismic data.

10 The least one data processing unit 6 (Fig. 1) carries out the steps of
11 establishing the at least first residual data set; mapping the at least first residual
12 data set on the two-dimensional grid; establishing the at least first-threshold
13 hydrocarbon intensity of interest; forming the at least a first, first-threshold
14 footprint; and superimposing the at least a first, first-threshold footprint over a
15 geological map of the subsurface formation within the terrain surveyed to readily
16 identify at least the location, size and shape of the terrain corresponding to the
17 subsurface formation of interest. Herein, the term “superposition” means relating
18 footprints or residual data sets with the geological features of the subsurface
19 formation. One form of superposition is to map the footprints on the geological
20 map of the subsurface formation

21 The processing unit 6 can comprise means for shifting the at least
22 one raw data set 100, 200 by a specified lag; means for removing noise from the
23 shifted at least one raw data set using filters; means for generating a baseline
24 103, 203 for the filtered at least one raw data to obtain residual amplitude

1 anomalies; means for subtracting the generated baseline from the filtered raw
2 data set to arrive at a least one residual data set 109, 209 containing residual
3 amplitude anomalies indicative of the hydrocarbon intensities contained in the
4 collected air samples. The processing unit further comprises means for
5 establishing the at least first-threshold hydrocarbon intensity of interest; means
6 for forming the at least a first, first-threshold footprint; and means for
7 superimposing the at least a first, first-threshold footprint over a geological map of
8 the subsurface formation within the terrain surveyed to readily identify at least the
9 location, size and shape of the terrain corresponding to the subsurface formation
10 of interest.

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Example 1

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A survey was conducted in South Australia. The results are shown in Figs. 9A-13. The aircraft used was a twin engine, low wing Piper Navajo. The scoop was located on the top of the fuselage of the aircraft forward of the engine. The aircraft was flown 100 meters above the terrain. The line spacing between the flight lines was 1 km. A section of the flight plan (two-dimensional grid) is illustrated in Fig. 5A of the accompanying drawings. The average flight parameters were as follows:

Speed of the aircraft 282.0 km/hr

Wind speed 20.5 km/hr

Ground speed 280.5 km/hr

Total flying time 9hr58min

The air samples were collected by the scoop illustrated by Figs. 2A, 2B and 2C of the accompanying drawings and the amount of methane ions and propane ions were detected by the detectors at 1 second intervals. A DCD detector was used to detect the methane ions. A photoionisation detector was used to detect the propane ions. The total number of hydrocarbon ions detected in the collected air samples for each interval along a flight line by the first detector (DCD) (which are essentially methane ions) was associated with location co-ordinates to form the first raw data set. The propane ions detected in the collected air samples by the second detector (PID) for each interval along a flight line was associated with location co-ordinates to form the second raw data set. The GPS navigation system used was a Novatel OEM3 Millennium GPSCard. The

1 first set and second set of raw data and the flight parameters were analyzed
2 further by a processing unit to arrive at first and second residual data sets which
3 correspond to methane and propane intensities.

4 Schematic representations of the data analysis (isolation of residual
5 amplitude anomalies) steps for methane and propane ions are shown in Figs. 6A
6 through 6F and 7A through 7F, respectively of the accompanying drawings. The
7 steps involved in the analysis were as follows:

8 With reference to Figs. 6A and 7A for the first and second raw data
9 sets 100, 200 respectively, the start fiducials were shifted by 3 seconds.

10 With reference to Figs. 6B and 7B, the two raw data sets were
11 resampled. The resampling interval was chosen to be 80 meters. This was
12 calculated by taking the average speed of the aircraft over several flight lines.

13 With reference to Figs. 6C and 7C, the two resampled data sets
14 101, 201 were passed through filters to get rid of noise. The filter used for the
15 noise reduction was a normal distribution filter.

16 With reference to Figs. 6D and 7D, a computer generated baseline
17 103, 203 was generated for each of the filtered (smoothed) data sets 102, 202.
18 This was generated by identifying vertices 104, 204 separating individual
19 amplitude anomalies and joining the identified vertices. The algorithm used for
20 generation of the baseline has been defined in the description.

21 With reference to Figs. 6E and 7E, the above baselines 103, 203
22 were inspected to check vertices that the computer generated baseline either
23 incorrectly identified or failed to detect. The vertices were then joined together by
24 straight lines resulting in a refined baseline 103r, 203r for each data set.

1 With reference to Figs. 6F and 7F, the refined baselines 103r, 203r
2 were subtracted from the filtered raw data sets (refer step 3) to arrive at a
3 residual data set 109, 209 corresponding to each of the two original raw data
4 sets, which are indicative of the methane and propane microseep intensities
5 (residual amplitude anomalies) contained in the collected air samples.

6 With reference to Fig. 5B, the first and second residual data sets
7 established for all the flight lines 30 are mapped on the discontinuous two-
8 dimensional grid 31 formed by the flight lines to show the areal distribution and
9 intensity of the microseep signal over the entire survey area.

10 The data surface was mapped and checked for consistency as well
11 as any baselining errors before proceeding.

12 Footprints were formed by establishing a first-threshold value,
13 second-threshold value, third-threshold value and fourth-threshold value. The
14 first, second, third and fourth threshold values chosen were top 25%, top 15%,
15 top 10% and top 5% of the hydrocarbon intensities represented by the residual
16 data sets, respectively. Examples of first through fourth-threshold values are
17 shown in Figs. 9A-10B and a legend is shown in Fig. 13.

18 Data points (equal-intensity data points) in the two-dimensional grid,
19 relatably adjacent one another and having intensities equal to the specified
20 threshold values were identified and associated to form methane footprints and
21 propane footprints. An example for formation of footprints for one threshold value
22 is illustrated in Figs. 8A and 8B. Fig. 9A illustrates footprints formed for four
23 different threshold values.

1 Footprints corresponding to the methane and propane intensities
2 were mapped on the same section of the flight plan illustrated in Fig. 5A or on
3 separate sections for clarity.

4 With reference to Fig. 9A, the footprints for methane are illustrated
5 superimposed on the flight plan of Fig. 5A. Then, with reference to Fig. 9B, the
6 methane footprints were also superimposed on the geological map of the
7 subsurface formation within the area surveyed. Each methane footprint is
8 represented by a stacked footprint representing the first-threshold footprint,
9 second-threshold footprint, third-threshold footprint and fourth-threshold footprint,
10 more specifically as shown in the legend of Fig.13.

11 Similarly, with reference to Figs. 10A and 10B, respectively, the
12 propane footprints are superimposed on the flight plan of Fig. 5A and
13 superimposed on the geological map of the subsurface formation.

14 The following parameters were easily identified from the
15 superimposed geological maps: location of the detected subsurface reservoirs;
16 type of the subsurface reservoirs; size, shape and orientation of the subsurface
17 reservoir; and prospectivity of the subsurface reservoir according to the defined
18 thresholds.

19 No further analysis is required for the identification of the above
20 stated parameters.

21 A 3-D seismic survey of the area, where the commercially
22 exploitable hydrocarbon footprints were located, and the 3-D seismic dataset
23 were scrutinized to accurately predict the geological zone of interest as well as its
24 approximate depth. Fig. 14 is a representation where the propane intensities for

1 one flight line are coupled with the seismic data collected from a 3-D seismic
2 survey of the geological area where the commercially viable propane footprints
3 are located.

4

5 Example 2

6 The same steps described in Example 1 were repeated except that
7 the one of the higher order hydrocarbon ions, in addition to propane ions, was
8 detected using a third detector. The third detector used was a photoionisation
9 detector and it was used to detect pentane ions. The data was analyzed to obtain
10 pentane footprints. With reference to Figs. 11A and 11B, respectively, the
11 pentane footprints are superimposed on the flight plan of Fig. 5A and
12 superimposed on the geological map of the subsurface formation.

13 According to another embodiment of the invention the detector
14 array detects either methane ions or at least one higher order hydrocarbon ions.

15 The higher order hydrocarbons present in the collected air samples
16 are propane or butane or pentane or hexane or mixtures thereof.

1 **THE EMBODIMENTS OF THE INVENTION IN WHICH AN**
2 **EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS**
3 **FOLLOWS:**
4

5 1. A method for the detection and categorization of
6 hydrocarbon deposits in subsurface formations comprising:

7 traversing a plurality of flight lines over terrain to be surveyed for
8 establishing a two-dimensional grid over the terrain which corresponds to the
9 subsurface formations therebelow;

10 collecting air samples along the flight lines;

11 counting hydrocarbon ions present in the collected air samples for
12 each of a plurality of location co-ordinates along the flight lines for establishing at
13 least one raw data set of the hydrocarbon ion count at each of the plurality of
14 location co-ordinates;

15 isolating amplitude anomalies from the at least one raw data set for
16 establishing at least a first residual data set of data points, each data point being
17 indicative of the hydrocarbon intensity at each of the plurality of location co-
18 ordinates in the two-dimensional grid;

19 mapping the at least first residual data set on the two-dimensional
20 grid;

21 establishing at least a first-threshold hydrocarbon intensity of
22 interest;

23 identifying data points relatably adjacent one another within the two-
24 dimensional grid and having intensities equal to the first-threshold hydrocarbon
25 intensity;

1 associating such equal- intensity data points to form at least a first,
2 first-threshold footprint which encompasses the equal-intensity data points and
3 any greater-intensity data points having intensities greater than the first-threshold
4 hydrocarbon intensity; and

5 superimposing the at least a first, first-threshold footprint over a
6 geological map of the subsurface formation within the terrain surveyed to readily
7 identify at least the location, size and shape of the terrain corresponding to the
8 subsurface formation of interest.

9

10 2. The method of claim 1 further comprising:

11 forming at least a subsequent first-threshold footprint by associating
12 equal-intensity data points relatably adjacent one another within the two-
13 dimensional grid and having intensities equal to the first-threshold hydrocarbon
14 intensity; and

15 superimposing the at least a subsequent first-threshold footprint
16 over a geological map of the subsurface formation within the terrain surveyed to
17 readily identify at least the location, size and shape of the terrain corresponding
18 to the subsurface formation of interest.

19

20 3. The method of claim 1 or 2 further comprising:

21 establishing at least a second-threshold hydrocarbon intensity of
22 interest, the second-threshold hydrocarbon intensity being higher than the first-
23 threshold hydrocarbon intensity;

1 identifying equal intensity data points relatably adjacent one another
2 within the two-dimensional grid and having intensities equal to the second-
3 threshold hydrocarbon intensity; and

4 associating such data points to form at least a first, second-
5 threshold footprint which encompasses data points having intensities equal to the
6 second-threshold hydrocarbon intensity or data points having intensities greater
7 than the second-threshold hydrocarbon intensity.

8

9 4. The method of claim 3 further comprising:

10 forming at least a subsequent second-threshold footprint; and

11 superimposing the at least subsequent second-threshold footprint
12 over a geological map of the subsurface formation within the terrain surveyed to
13 readily identify at least the location, size and shape of the terrain corresponding
14 to the subsurface formation of interest.

15

16 5. The method of claim 3 or 4 further comprising:

17 establishing at least a first-threshold areal extent for at least a first ,
18 first-threshold footprint and at least a first, second-threshold footprint; and

19 superimposing only those first-threshold footprints and second-
20 threshold footprints at or above the at least first threshold areal extent over a
21 geological map of the subsurface formation within the terrain surveyed to readily
22 identify at least the location, size and shape of the terrain corresponding to the
23 subsurface formation of interest.

24

1 6. The method of any one of claims 1 to 5 wherein the counting
2 of the hydrocarbon ions comprises counting substantially methane ions.

3

4 7. The method of claim 6 wherein the methane ions are
5 counted using a direct current discharge spectral emission type detector.

6

7 8. The method of claim 6 or 7 wherein the at least one raw data
8 set of hydrocarbon ion count corresponds to the count of methane ions.

9

10 9. The method of any one of claims 1 to 5 wherein the counting
11 of the hydrocarbon ions comprises counting at least one higher order
12 hydrocarbon ions.

13

14 10. The method of claim 9 wherein the at least one higher order
15 hydrocarbon ions are counted using a photoionization detector.

16

17 11. The method of claim 9 or 10 wherein the at least one higher
18 order hydrocarbons are propane.

19

20 12. The method of any one of claims 9 to 11 wherein the at least
21 one raw data set of hydrocarbon ion count corresponds to the count of the at
22 least one higher order hydrocarbon ions.

23

1 13. The method of claim 9 wherein the counting of the
2 hydrocarbon ions further comprises counting a second higher order hydrocarbon
3 ions.

4

5 14. The method of claim 13 wherein the second higher order
6 hydrocarbons are pentane.

7

8 15. The method of any one of claims 1 to 5 wherein the counting
9 of the hydrocarbon ions comprises counting methane ions and at least one higher
10 order hydrocarbon ions.

11

12 16. The method of any one of claims 1 to 5, and 15 wherein the
13 at least one raw data set of hydrocarbon ion count comprises a first data set
14 corresponding to the count of the methane ions and a second raw data set
15 corresponding to the count of the at least one higher order hydrocarbon ions.

16

17 17. The method of any one of claims 9 to 16 wherein the at least
18 one higher order hydrocarbons are propane or butane or pentane or hexane or
19 mixtures thereof.

20

21 18. The method of any one of claims 1 to 17 wherein the aircraft
22 is flown about 0.1km above the subsurface formation to be surveyed.

23

1 19. The method of any one of claims 1 to 18 wherein maximum
2 distance between the flight lines is in the range of about one half to above one
3 kilometer.

4

5 20. The method of claim 19 wherein the maximum distance
6 between the flight lines is about one kilometer.

7

8 21. The method of any one of claims 1 to 20 wherein the flight
9 parameters transmitted include aircraft speed, wind speed and ground speed.

10

11 22. The method of any one of claims 1 to 21 wherein the
12 collected air samples are associated with location co-ordinates using a GPS
13 navigating system.

14

15 23. The method of claim 1 or 2 wherein
16 establishing the at least first residual data set;
17 mapping the at least first residual data set on the two-dimensional
18 grid;

19 establishing the at least first-threshold hydrocarbon intensity of
20 interest;

21 forming the at least a first, first-threshold footprint; and

22 superimposing the at least a first, first-threshold footprint over a
23 geological map of the subsurface formation within the terrain surveyed to readily
24 identify at least the location, size and shape of the terrain corresponding to the

1 subsurface formation of interest is carried out by at least one data processing
2 unit.

3

4 24. The method of claim 1, 2 or 23 wherein establishing the at
5 least a first residual data set comprises:

6 shifting the at least one raw data set by a specified lag;

7 removing noise from the at least one raw data set using filters;

8 generating a baseline for the at least one raw data to isolate
9 residual amplitude anomalies;

10 and subtracting the generated baseline from the filtered at least one
11 raw data set to arrive at the at least one residual data set; wherein the at least
12 one residual data set contains residual amplitude anomalies indicative of the
13 hydrocarbon intensities.

14

15 25. The method of any one of claim 24 wherein the specified lag
16 is in the range of non-zero seconds to about 6 seconds.

17

18 26. The method of claim 24 wherein the specified lag is 0
19 seconds.

20

21 27. The method of any one of claims 1 to 26 further comprising
22 counting of carbon dioxide ions or iodine ions.

23

1 28. A method for the detection and categorization of
2 hydrocarbon deposits in subsurface formations comprising:
3 traversing a plurality of flight lines over terrain to be surveyed for
4 establishing a two-dimensional grid over the terrain which corresponds to the
5 subsurface formations therebelow;
6 collecting air samples along the flight lines;
7 counting methane ions and at least one higher order hydrocarbons
8 ions present in the collected air samples for each of a plurality of location co-
9 ordinates along the flight lines for establishing at least a first raw data set of the
10 methane ion count and a second raw data set of the higher order hydrocarbon
11 ion count at each of the plurality of location co-ordinates;
12 isolating residual amplitude anomalies from the first raw data set
13 and second raw data set for establishing a first residual data set of first data
14 points, each first data point indicative of methane intensity and a second residual
15 data set of second data points, each second data point indicative of higher order
16 hydrocarbon intensity at each of the plurality of location co-ordinates in the two-
17 dimensional grid;
18 mapping the first residual data set and residual data set on the two-
19 dimensional grid;
20 establishing at least a first-threshold hydrocarbon intensity of
21 interest;
22 identifying first data points and second data points relatably
23 adjacent one another within the two-dimensional grid and having intensities equal
24 to the first-threshold hydrocarbon intensity;

1 associating such equal-intensity data points to form at least a first,
2 first-threshold methane footprint and at least a first, first-threshold at least one
3 higher order hydrocarbon footprint which encompasses the equal-intensity data
4 points or any greater-intensity data points having intensities greater than the first-
5 threshold hydrocarbon intensity; and

6 superimposing the at least a first, first-threshold methane footprint
7 and the at least a first, first-threshold at least one higher hydrocarbon footprint
8 over a geological map of the subsurface formation within the terrain surveyed to
9 readily identify at least the location, size and shape of the terrain corresponding
10 to the subsurface formation of interest.

11

12 29. An apparatus for the detection and categorization of
13 hydrocarbon deposits in subsurface formations comprising:

14 an aircraft with a scoop fitted thereon for traversing a plurality
15 of flight lines over terrain to be surveyed for establishing a two-dimensional grid
16 over the terrain which corresponds to the subsurface formations therebelow;

17 the scoop collecting air samples and focusing the ions
18 contained in the air samples towards a detector array;

19 the detector array comprising at least one detector for
20 counting hydrocarbon ions present in the collected air samples for each of a
21 plurality of location co-ordinates along the flight lines for establishing at least one
22 raw data set of the hydrocarbon ion count at each of the plurality of location co-
23 ordinates; and

1 at least one processing unit for receiving and analyzing the
2 at least one raw data set for creating footprints of interest indicative of the
3 hydrocarbon intensities contained in the collected air samples and superimposing
4 the footprints over a geological map of the subsurface formation within the terrain
5 surveyed to readily identify at least the location, size and shape of the terrain
6 corresponding to the subsurface formation of interest.

7

8 30. The apparatus as claimed in claim 29 wherein the scoop is
9 an electromagnetic focusing tube and comprises a pyramidal scoop having
10 converging walls, each wall formed of overlapping metal louvers for directing the
11 charged ions of the collected air samples towards a collection tube at
12 downstream apex, while permitting majority of the air to be discharged laterally
13 through the louvers.

14

15 31. The apparatus as claimed in claim 29 or 30 wherein the
16 scoop is conical.

17

18 32. The apparatus of any one of claims 29 to 31 wherein the
19 scoop is located on the aircraft in such a manner that unburned fuel from the
20 aircraft engine does not enter the scoop.

21

22 33. The apparatus as claimed in any one of claims 29 to 32
23 further comprises a separator located between the collection tube and the
24 detector array, the separator comprises a coiled tube whose one end is

1 connected to the collection tube and the other end is connected to the detector
2 array, at least one turn of the hollow tube having a tangential outlet for directing
3 unwanted particulate matter outwardly from the coiled tube.

4

5 34. The apparatus as claimed in any one of claims 29 to 33
6 wherein the detector array comprises a direct current discharge spectral emission
7 type detector or a photoionization detector.

8

9 35. The apparatus as claimed in any one of claims 29 to 34
10 wherein the detector array comprises a direct current discharge spectral emission
11 type detector and a photoionization detector.

12

13 36. The apparatus as claimed in any one of claims 29 to 35
14 wherein the at least one processing unit further comprises:

15 means for shifting the at least one raw data set by a specified lag;

16 means for removing noise from the shifted at least one raw data set
17 using filters;

18 means for generating a baseline for the filtered at least one raw
19 data to obtain residual amplitude anomalies;

20 means for subtracting the generated baseline from the filtered raw
21 data set to arrive at a least one residual data set containing residual amplitude
22 anomalies indicative of the hydrocarbon intensities contained in the collected air
23 samples.

24

1 37. The apparatus as claimed in any one of claims 29 to 36
2 wherein the detector array further comprises a detector for counting carbon
3 dioxide ions or iodine ions.

4
5 38. The apparatus as claimed in any one of claims 29 to 37
6 wherein the at least one processing unit is located in the aircraft or at a remote
7 location.

8
9 39. An apparatus for detection of hydrocarbon deposits in
10 subsurface formations comprising:

11 an aircraft with a scoop fitted thereon for traversing a plurality
12 of flight lines over terrain to be surveyed for establishing a two-dimensional grid
13 over the terrain which corresponds to the subsurface formations therebelow;

14 the scoop collecting air samples and focusing the ions
15 contained in the air samples towards a detector array;

16 the detector array comprising a first detector for counting
17 methane ions and a second detector for counting at least one higher order
18 hydrocarbon ions present in the collected air samples for each of a plurality of
19 location co-ordinates along the flight lines for establishing a first raw data set of
20 methane ion count and a second raw data set of the at least one higher order
21 hydrocarbon ion count at each of the plurality of location co-ordinates; and

22 at least one processing unit for receiving and analyzing the first and
23 second raw data sets for creating footprints of interest indicative of methane
24 intensities and at least one higher order hydrocarbon intensities contained in the

1 collected air samples and superimposing the footprints over a geological map of
2 the subsurface formation within the terrain surveyed to readily identify at least the
3 location, size and shape of the terrain corresponding to the subsurface formation
4 of interest.

5

6 40. The apparatus as claimed in claim 39 wherein the detector
7 array comprises a direct current discharge spectral emission type detector for
8 counting the methane ions and a photoionization detector for counting the at least
9 one higher order hydrocarbon ions.

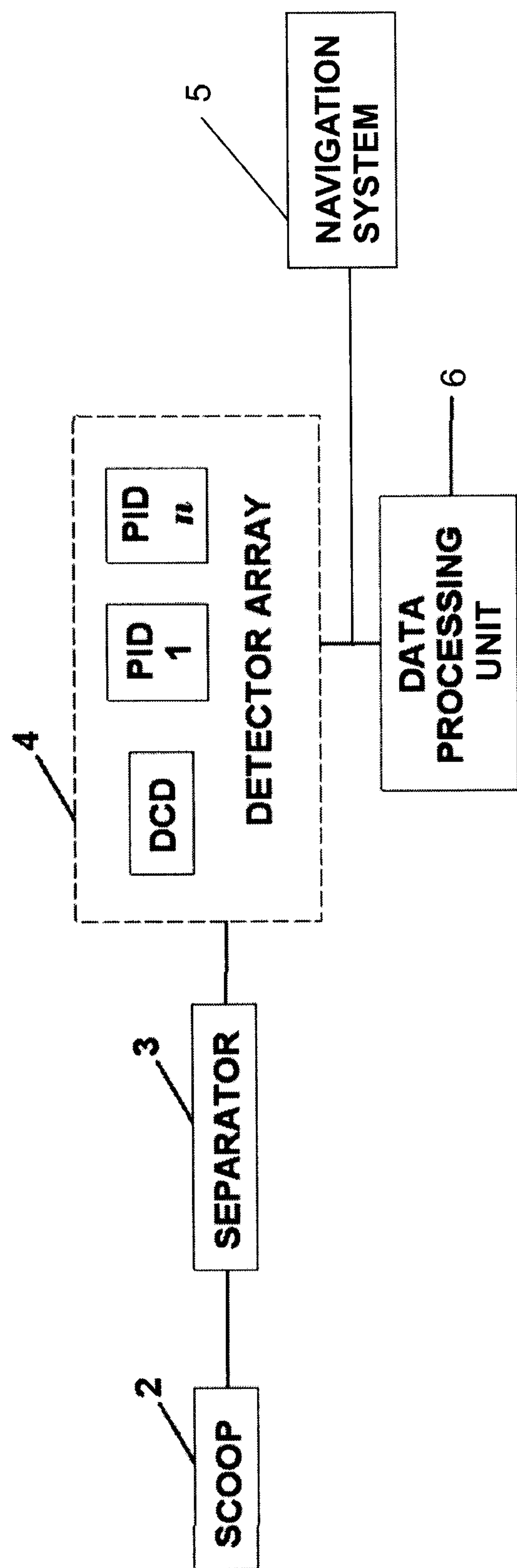


Fig. 1

Fig. 2A

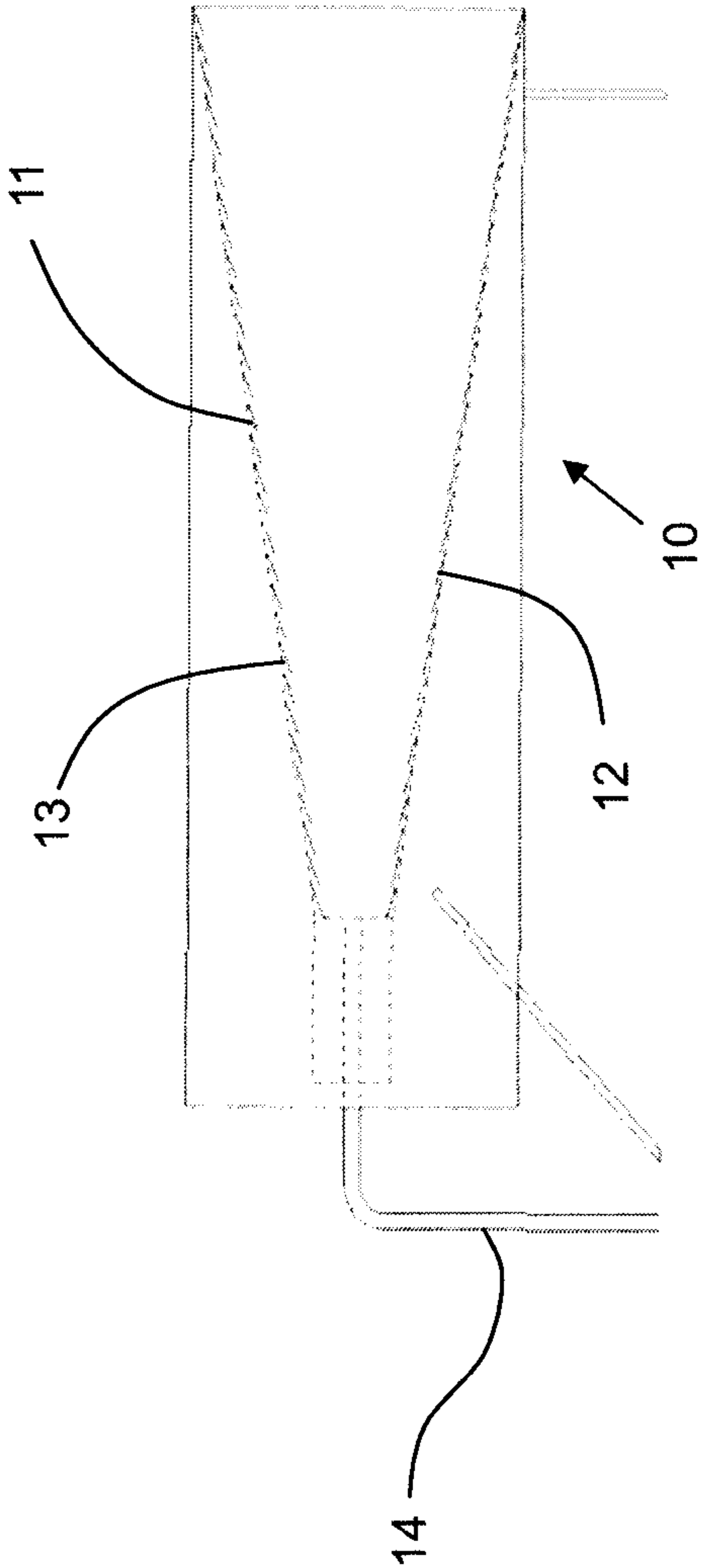


Fig. 2C

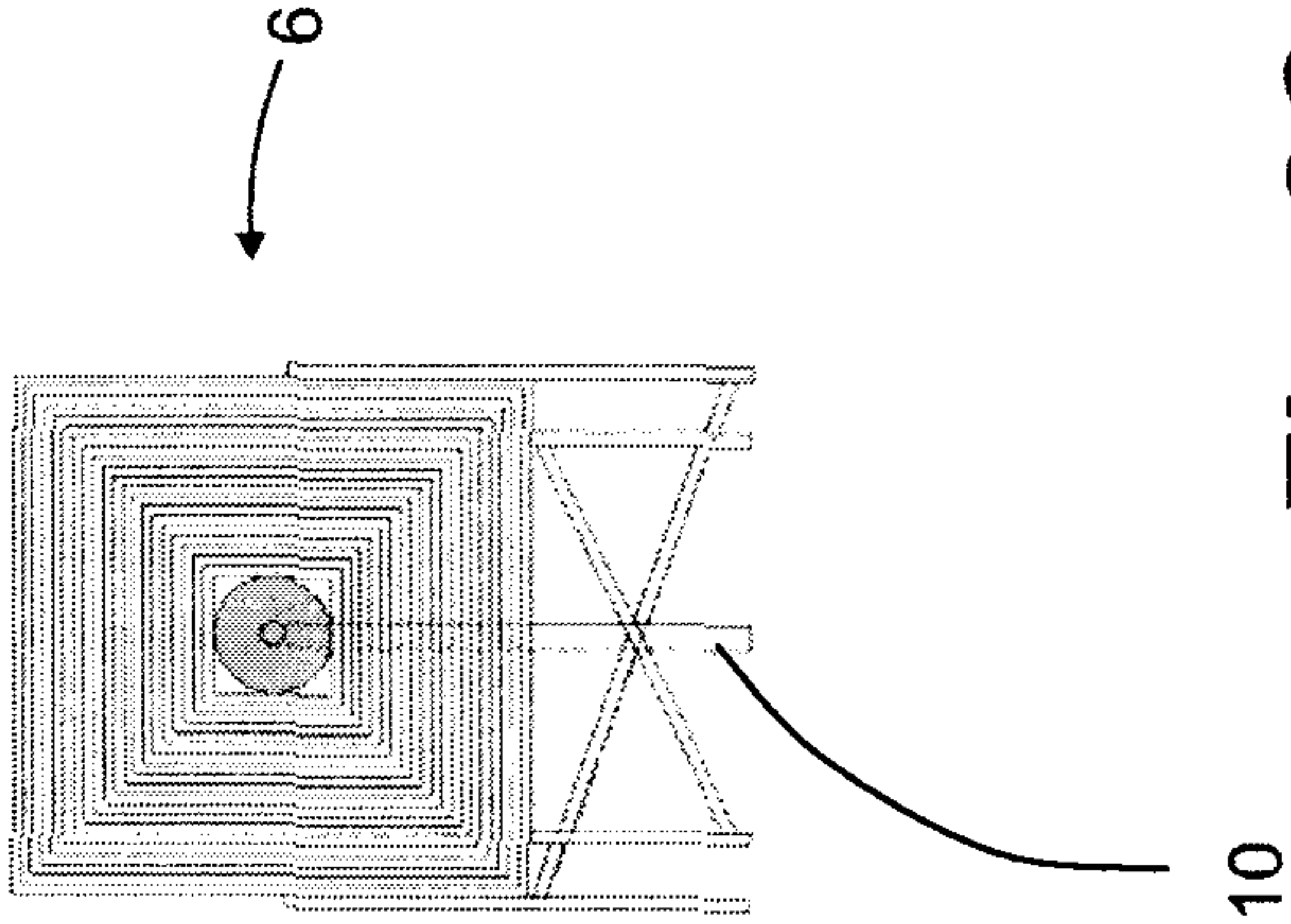
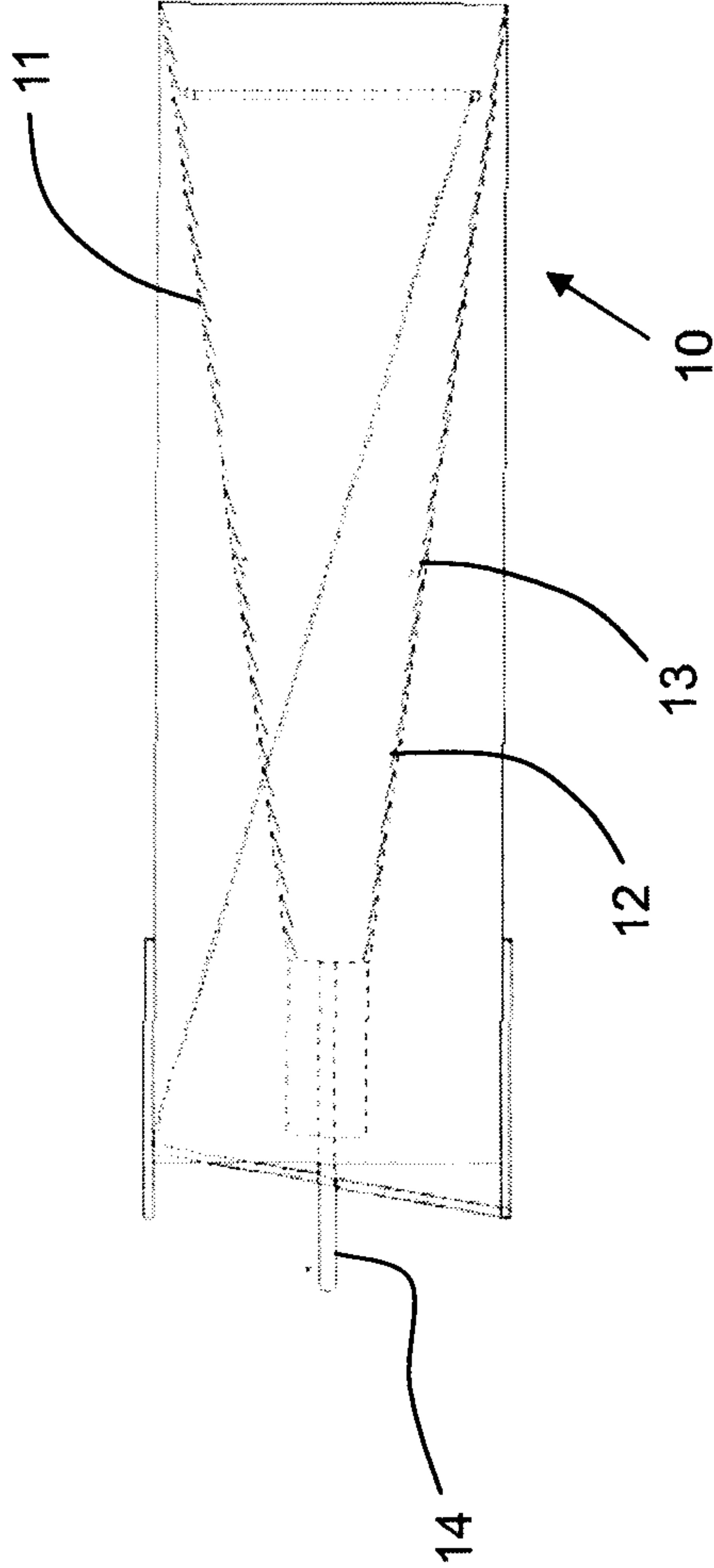
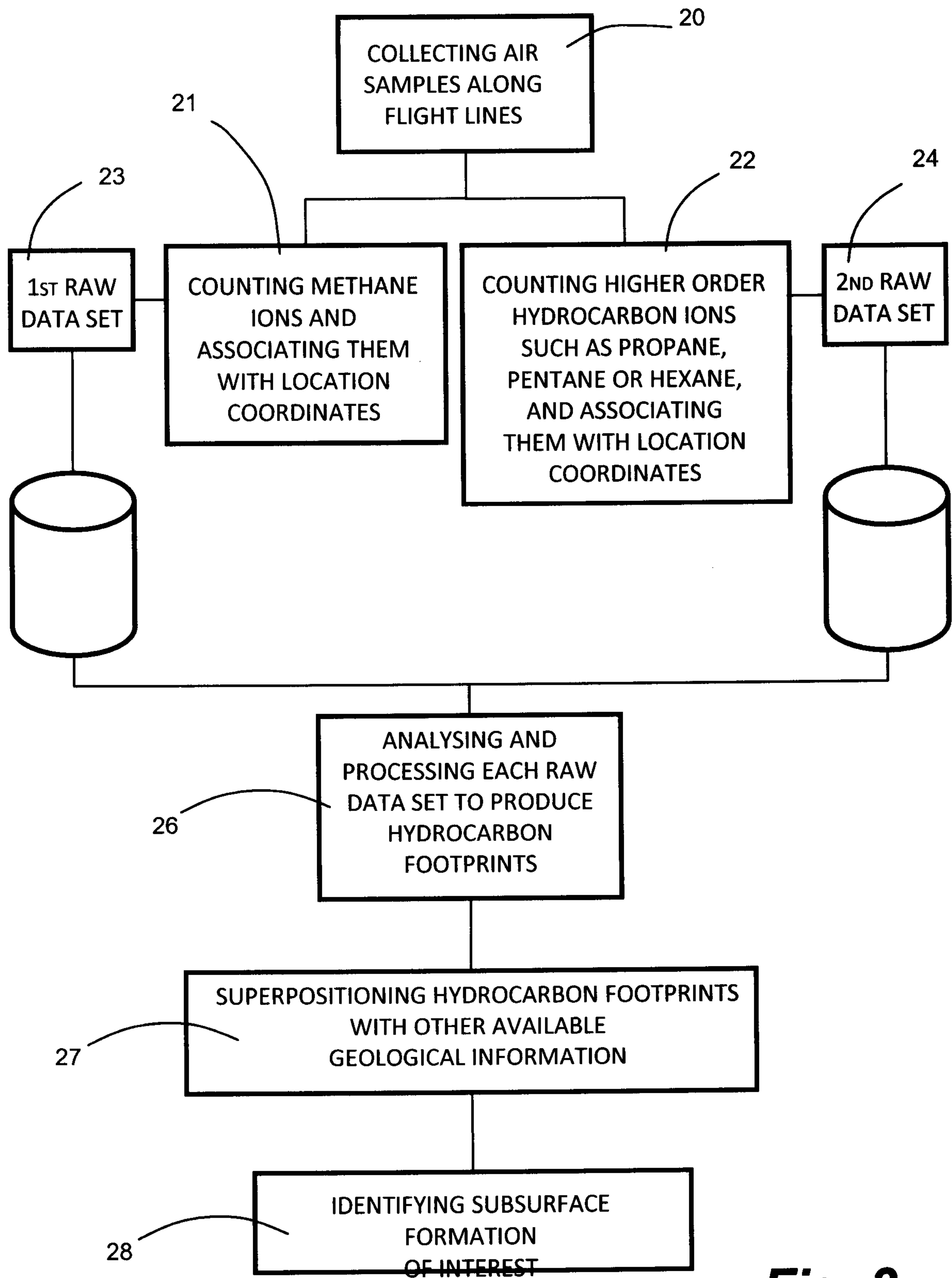


Fig. 2B



**Fig. 3**

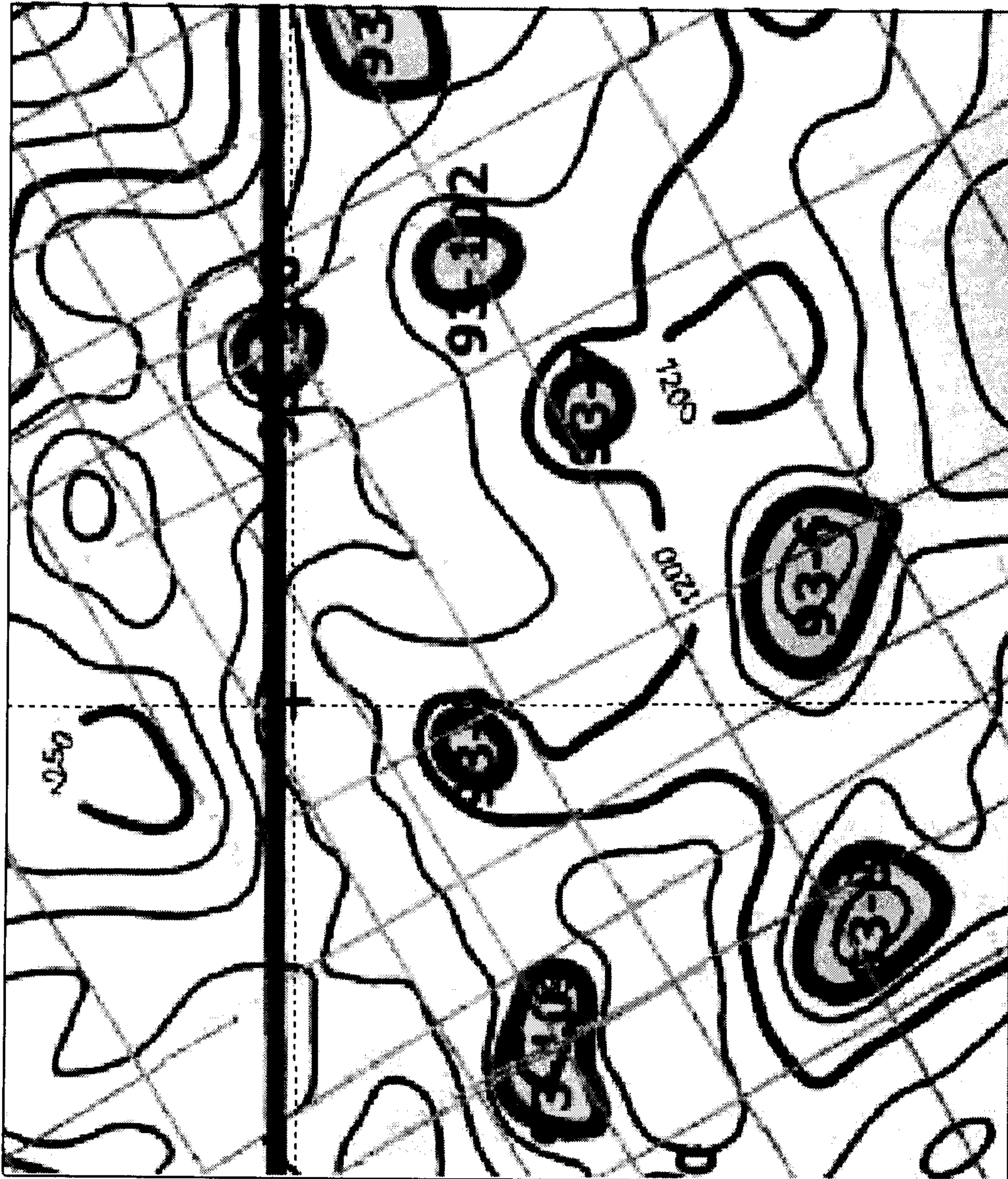


Fig. 4

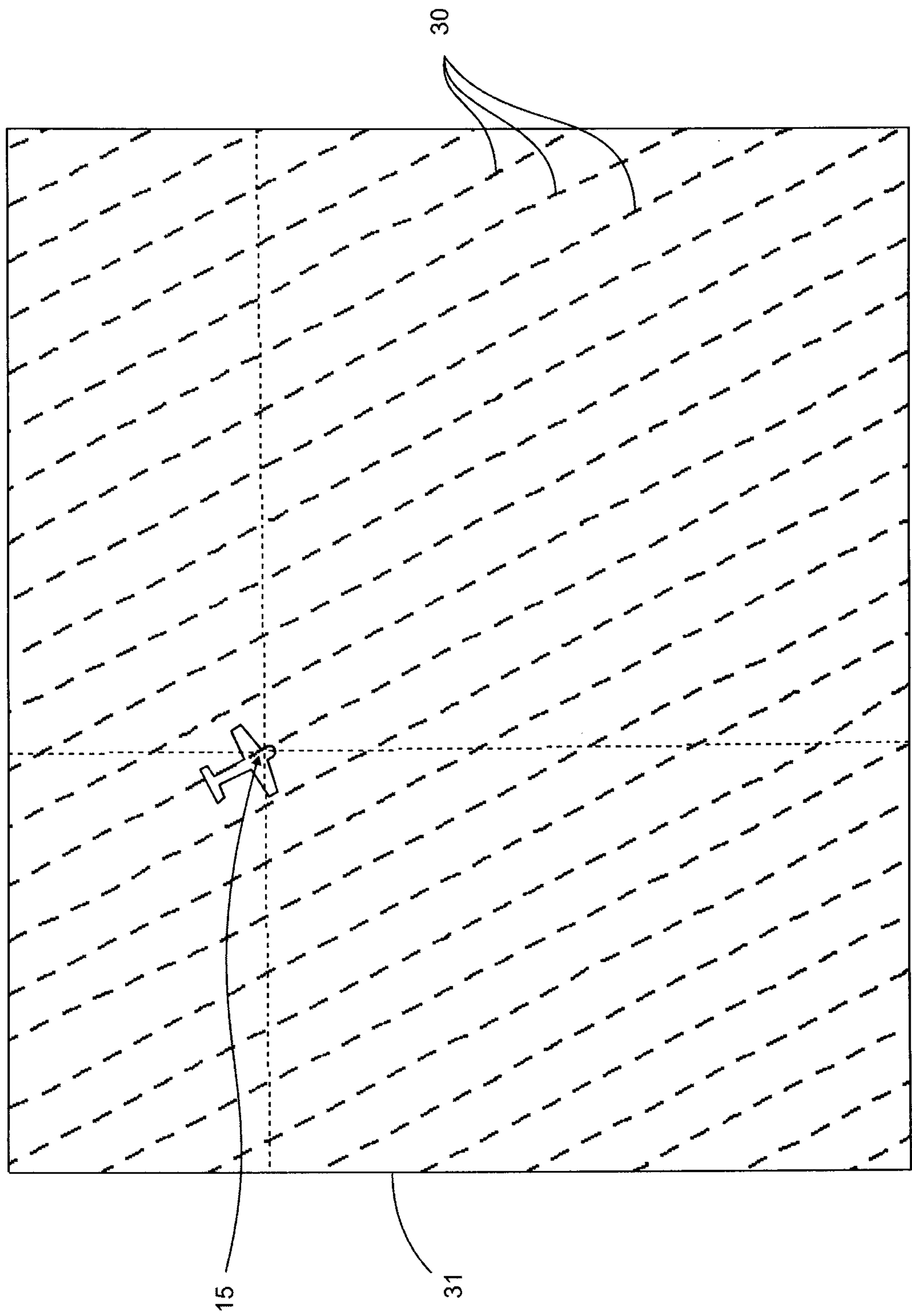


Fig. 5A

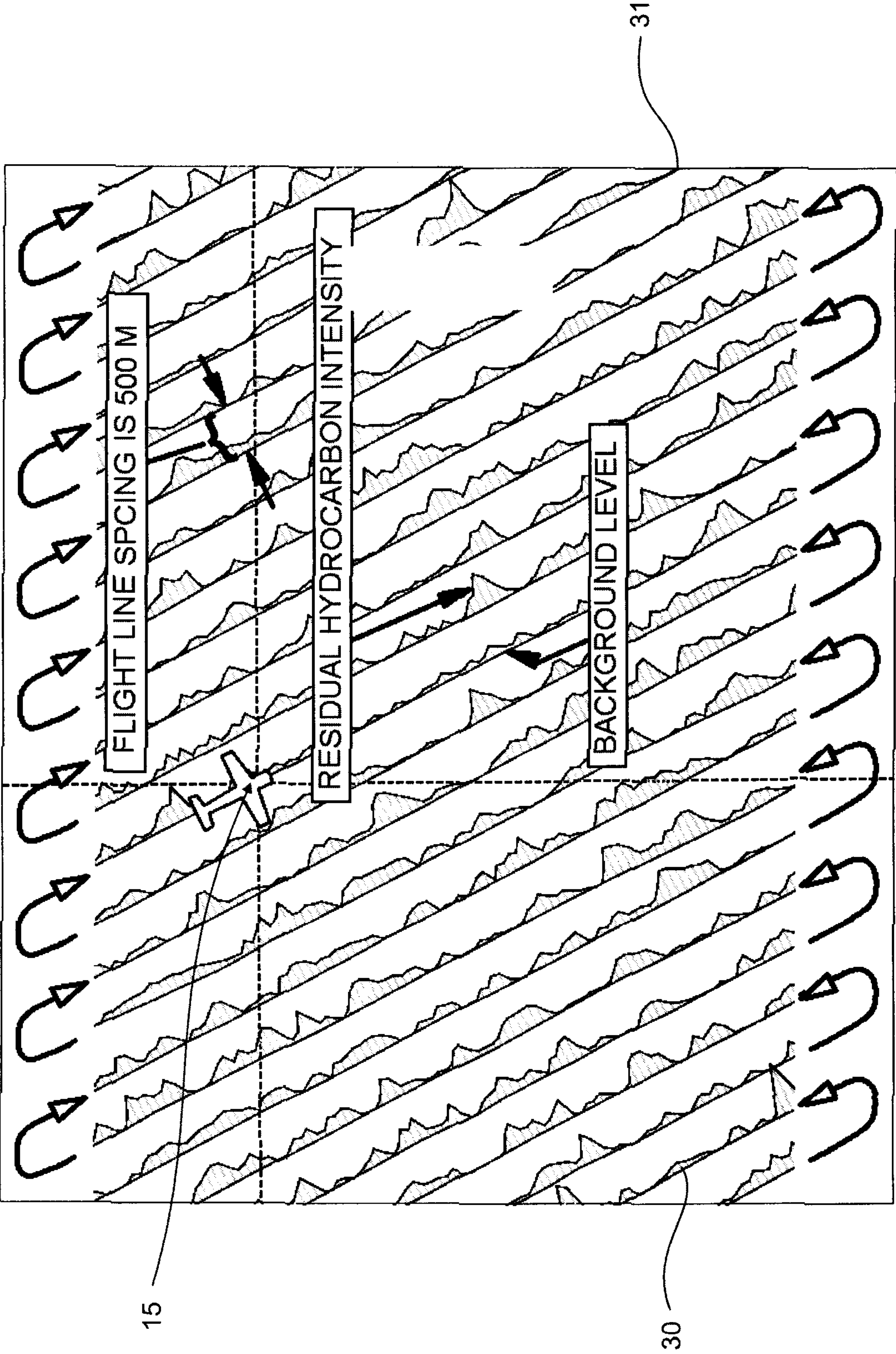


Fig. 5B

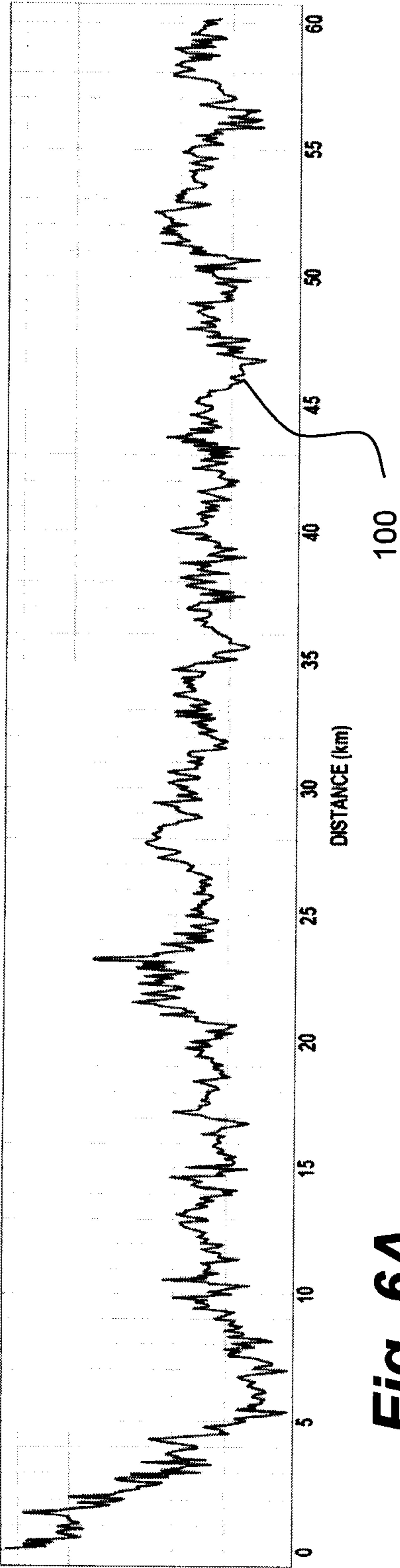


Fig. 6A

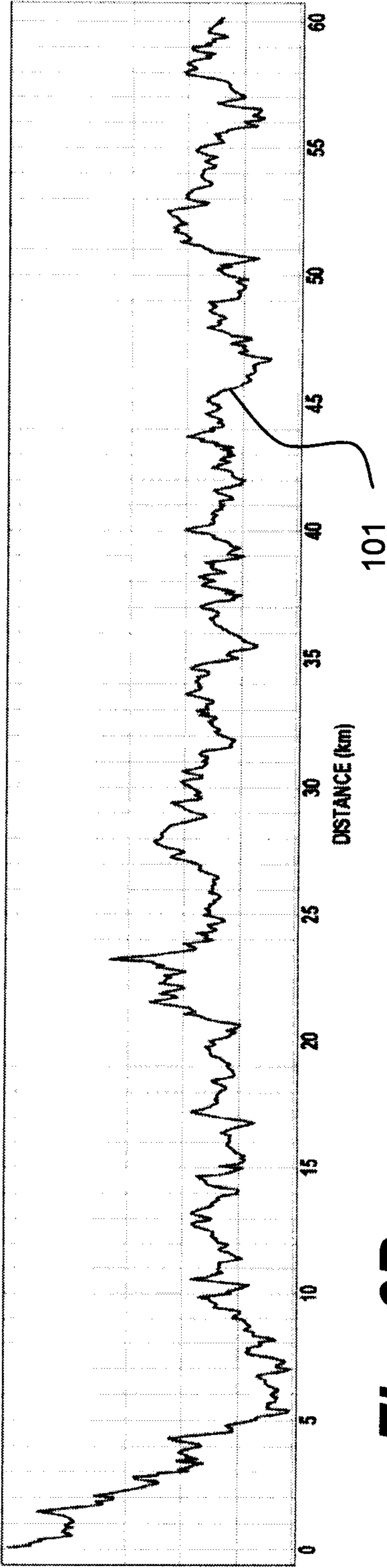


Fig. 6B

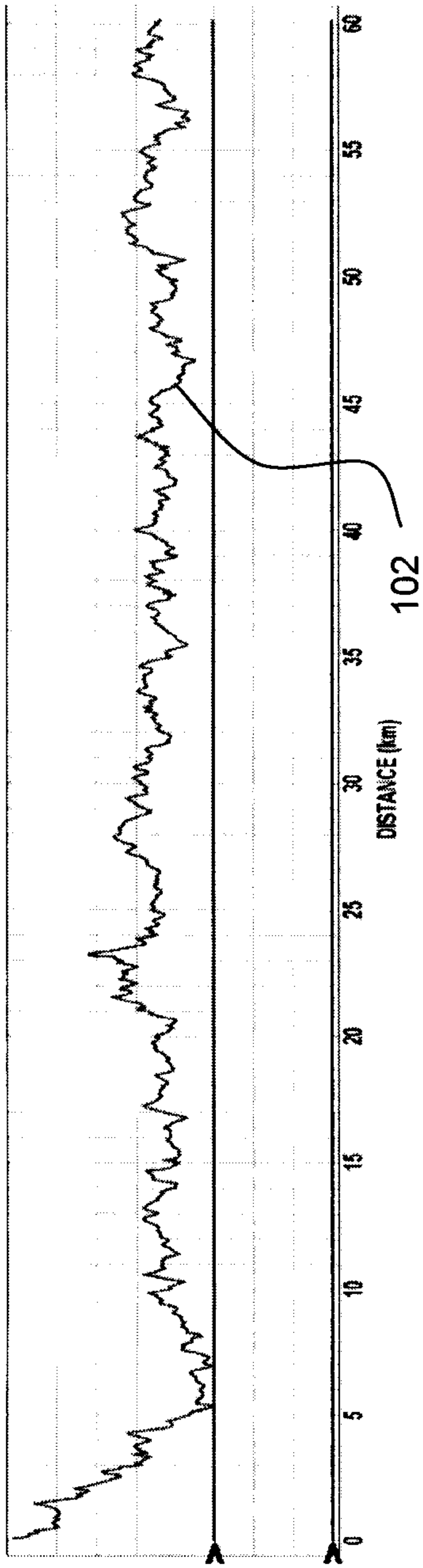


Fig. 6C

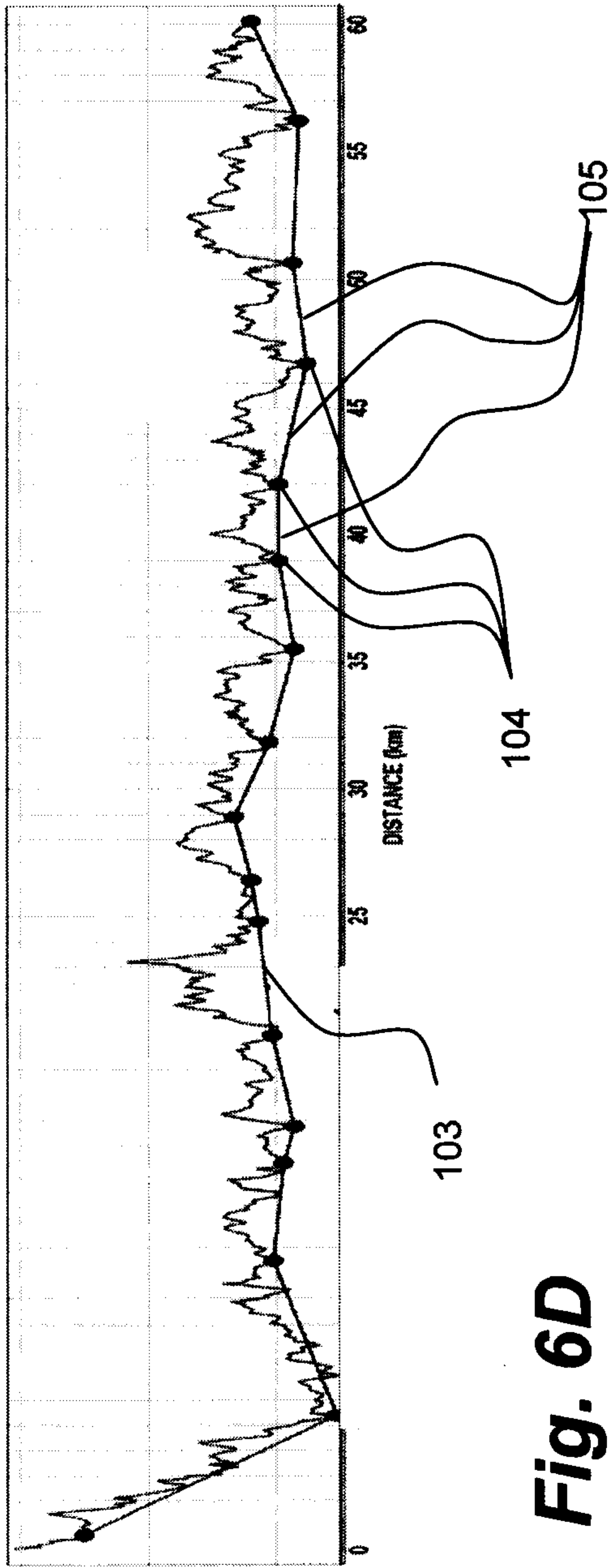


Fig. 6D

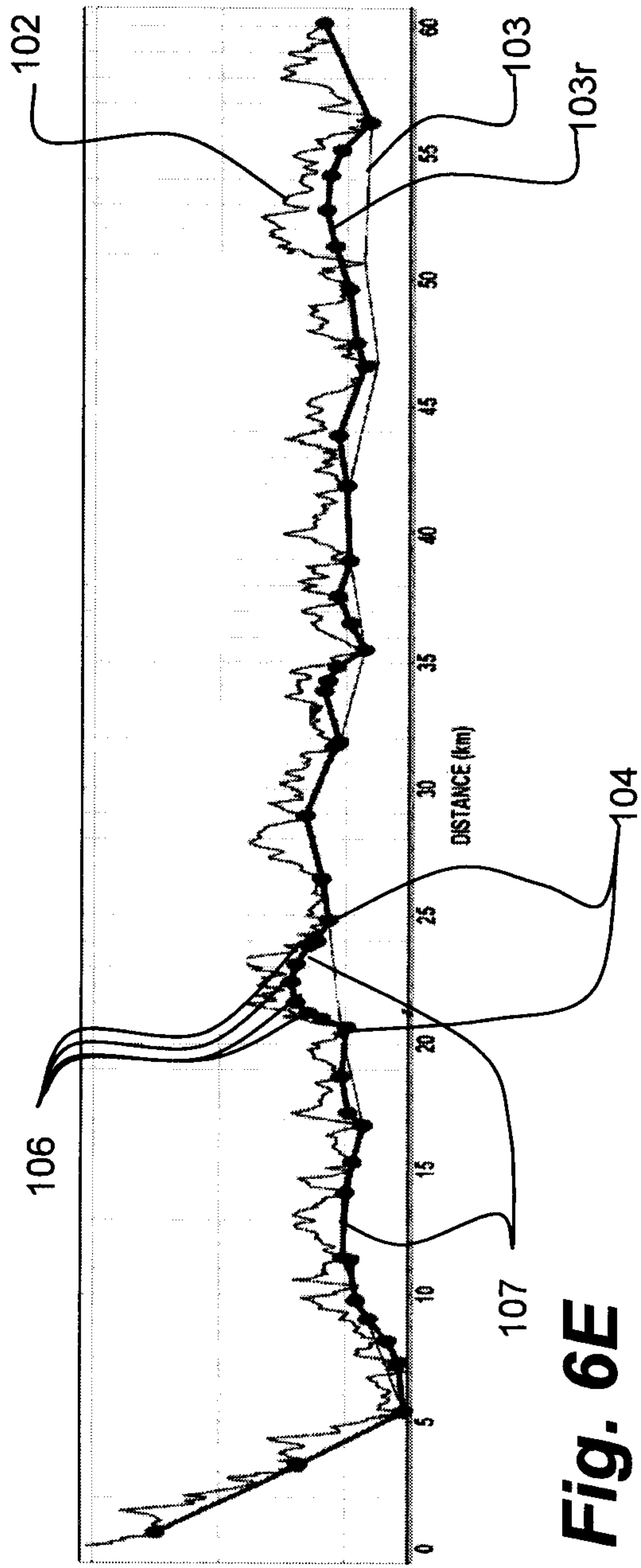


Fig. 6E

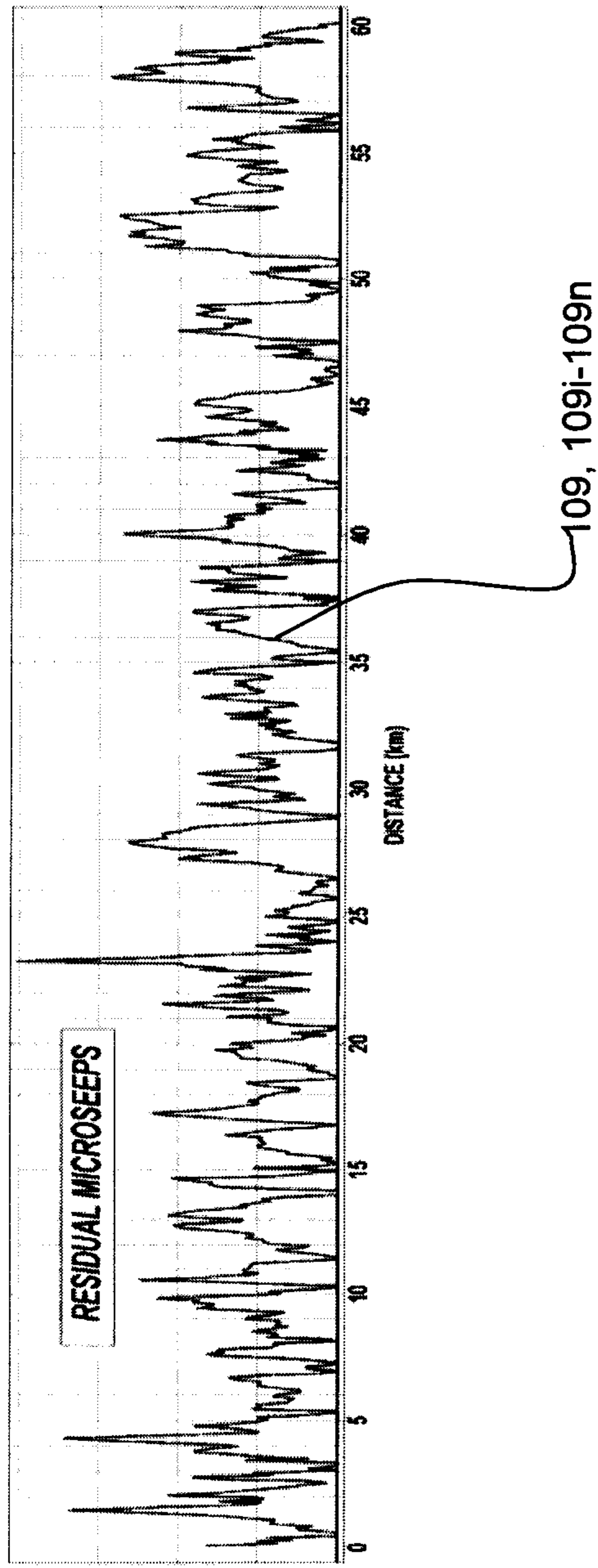


Fig. 6F

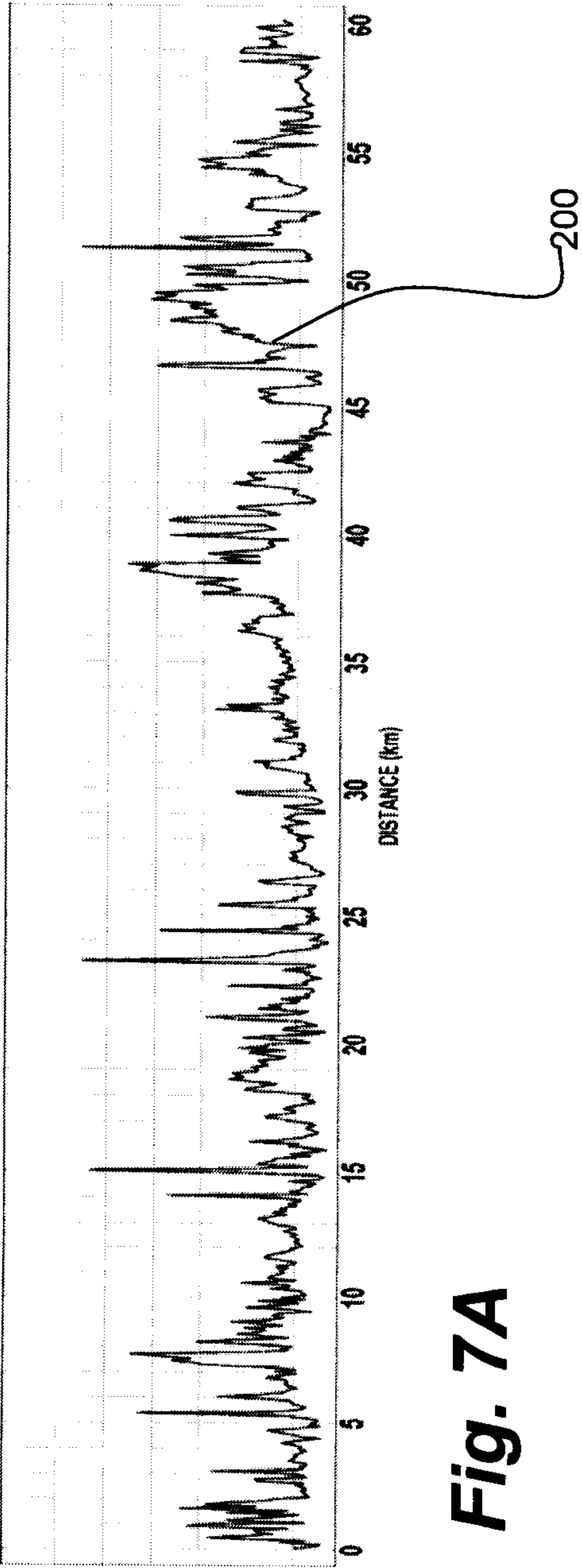


Fig. 7A

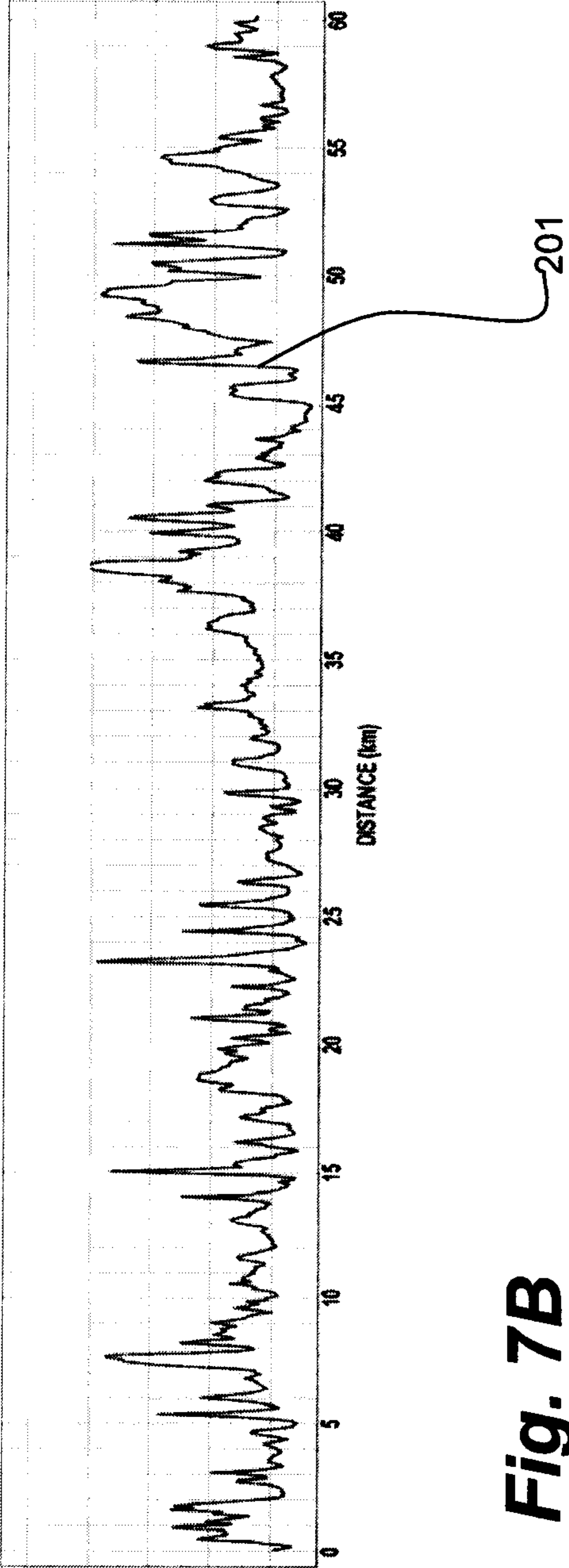
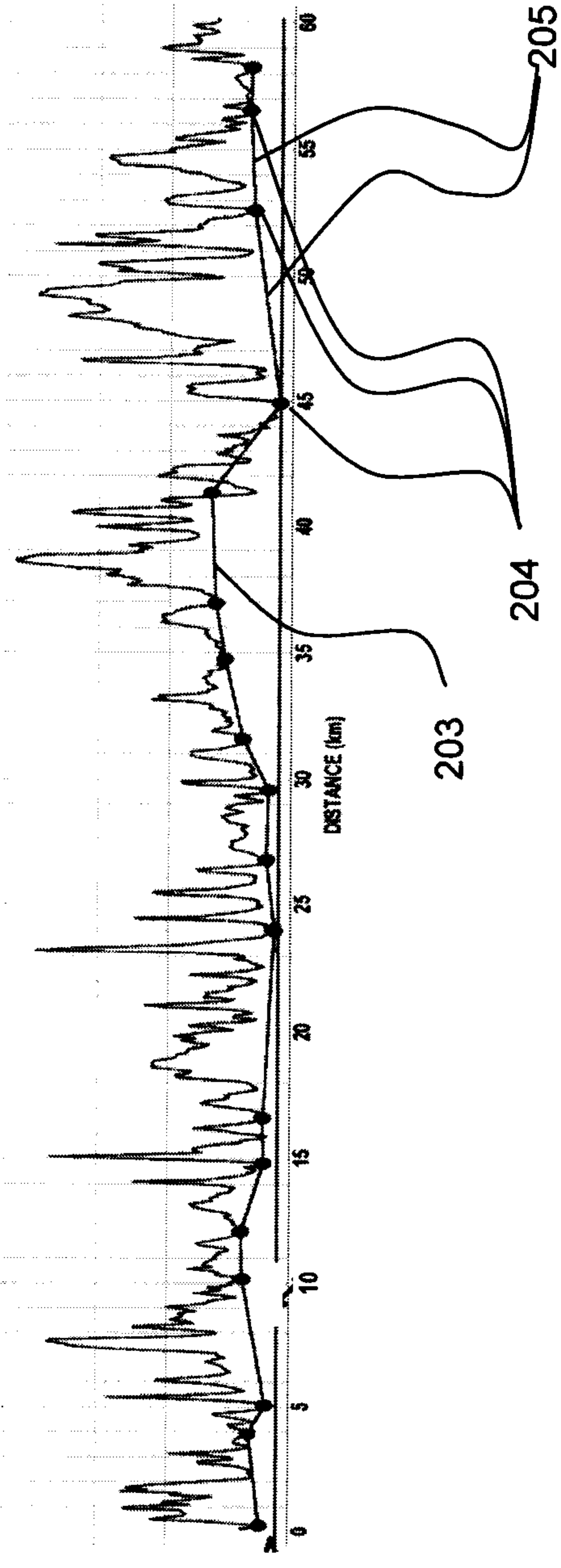
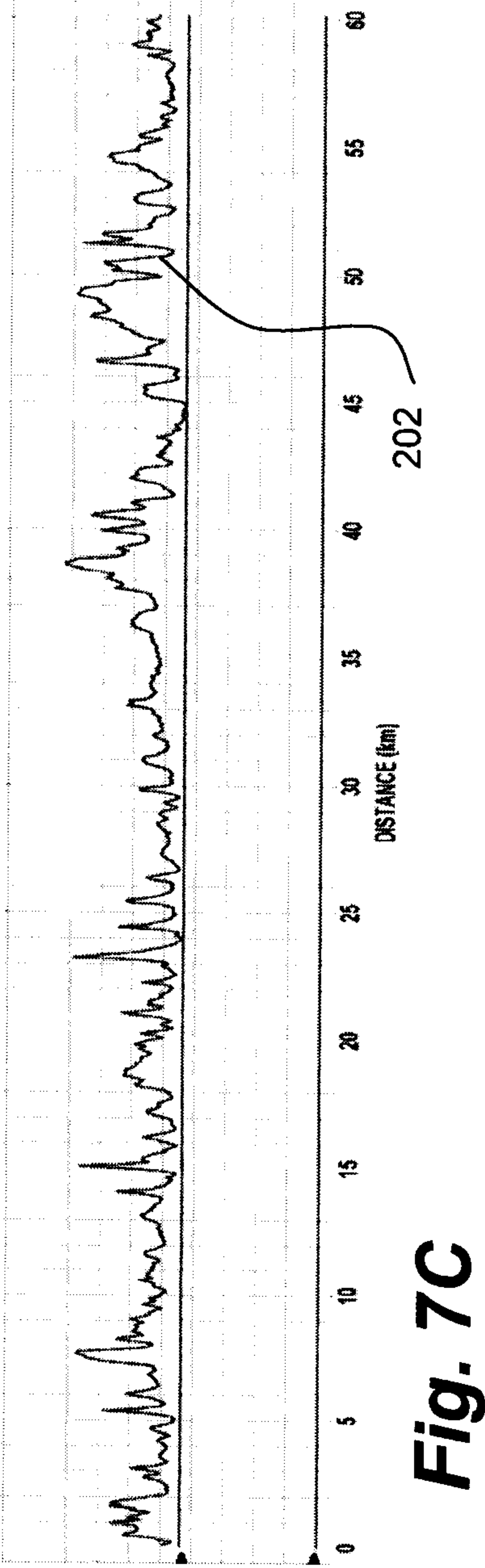


Fig. 7B



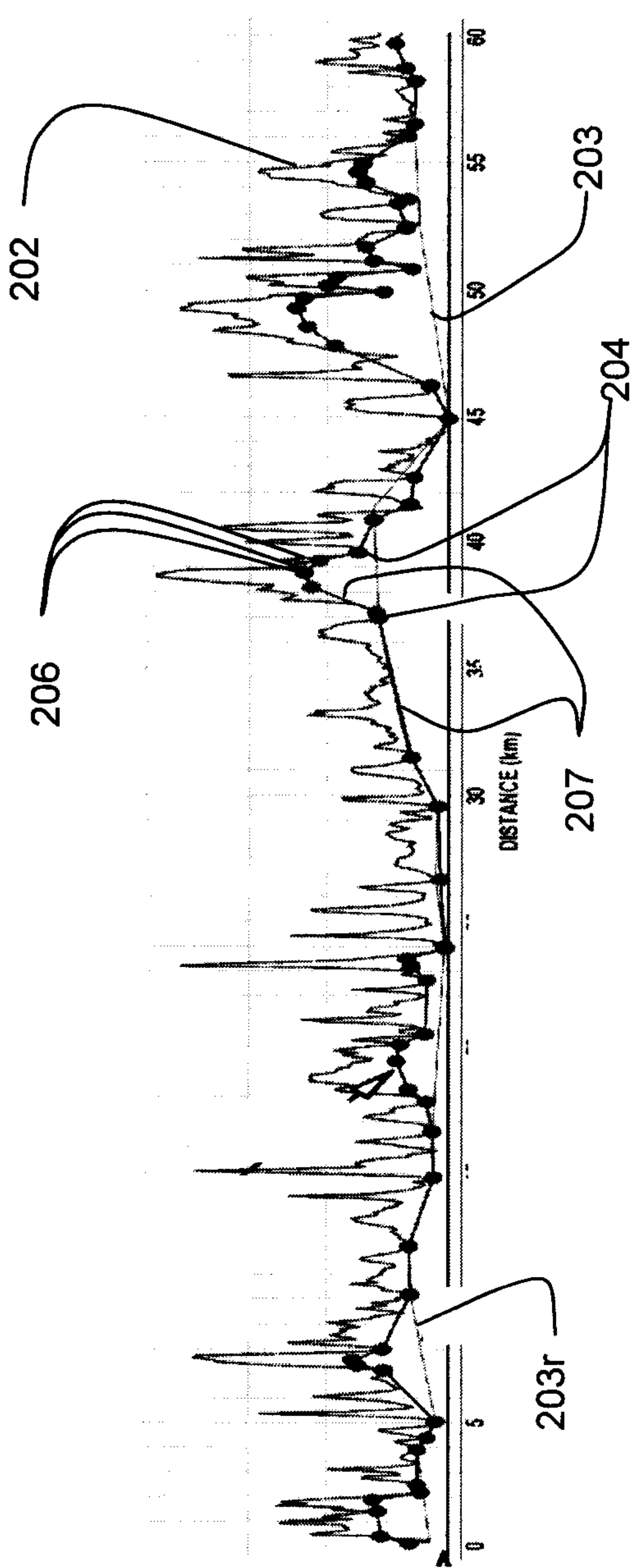


Fig. 7E

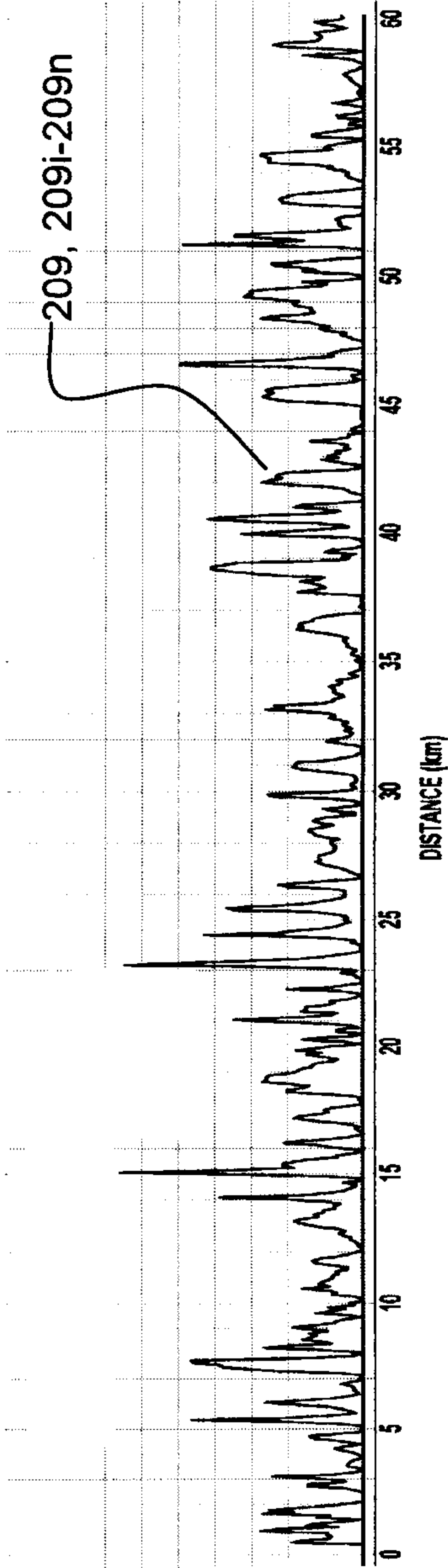


Fig. 7F

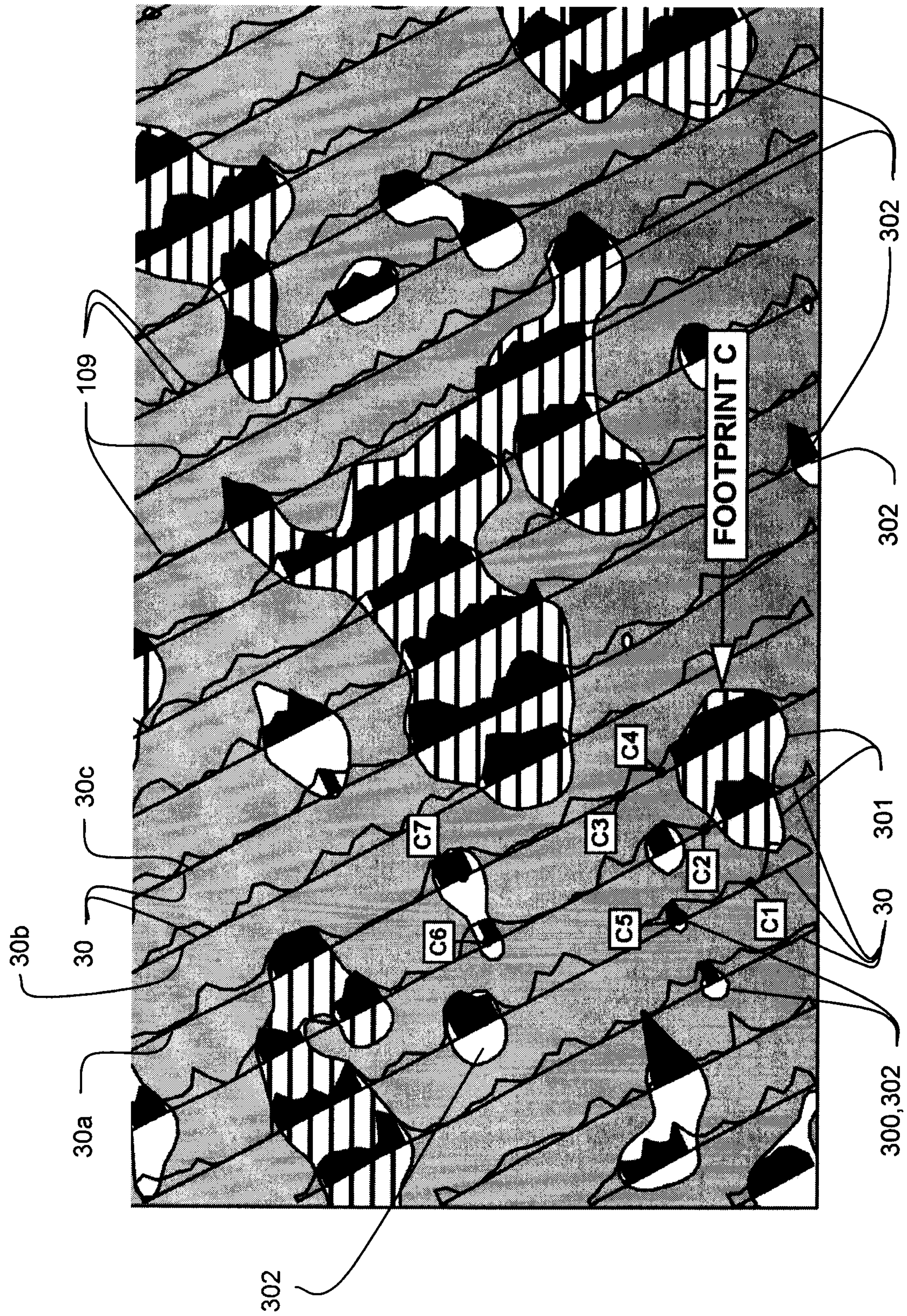


Fig. 8A

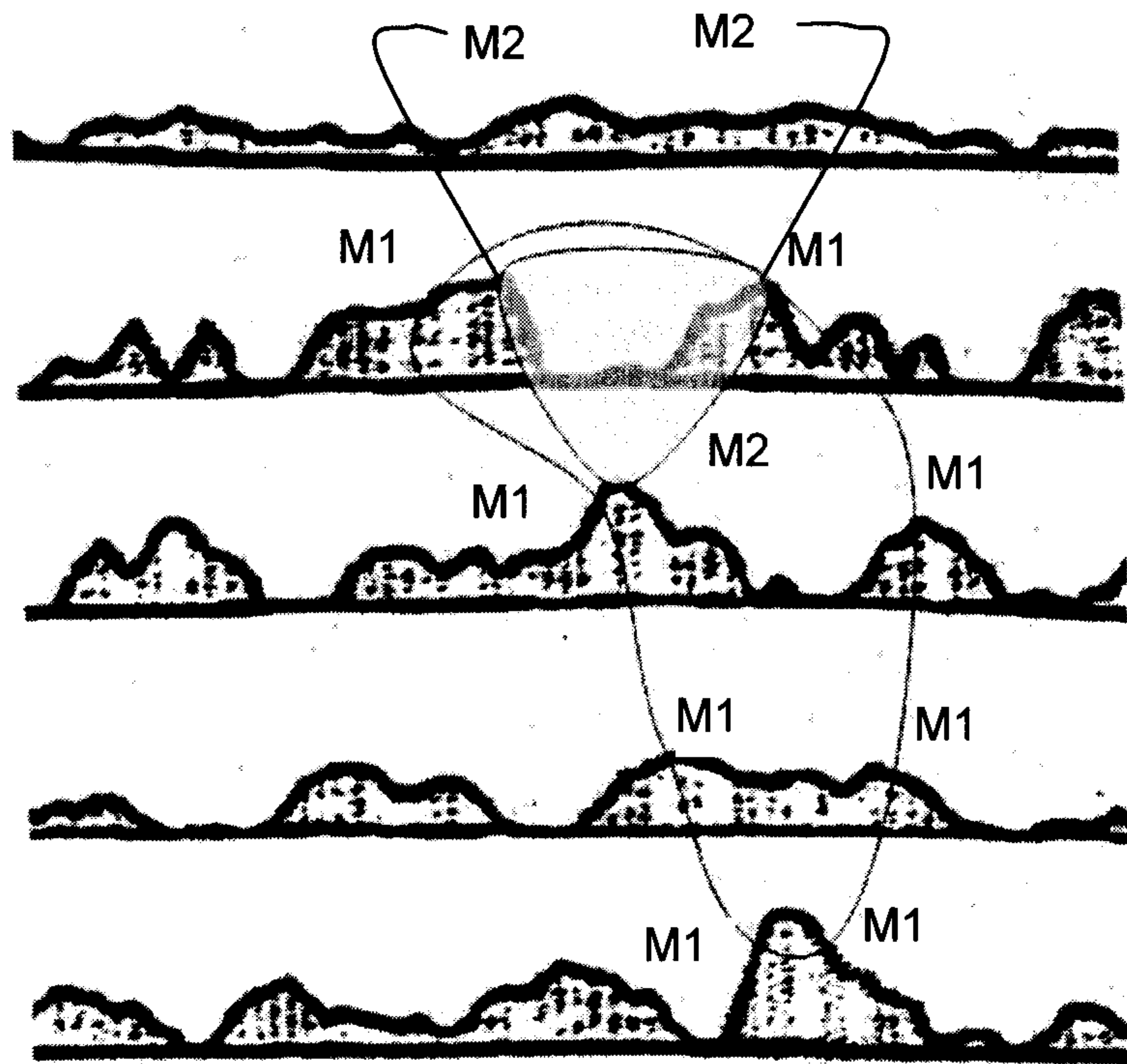


Fig. 8B

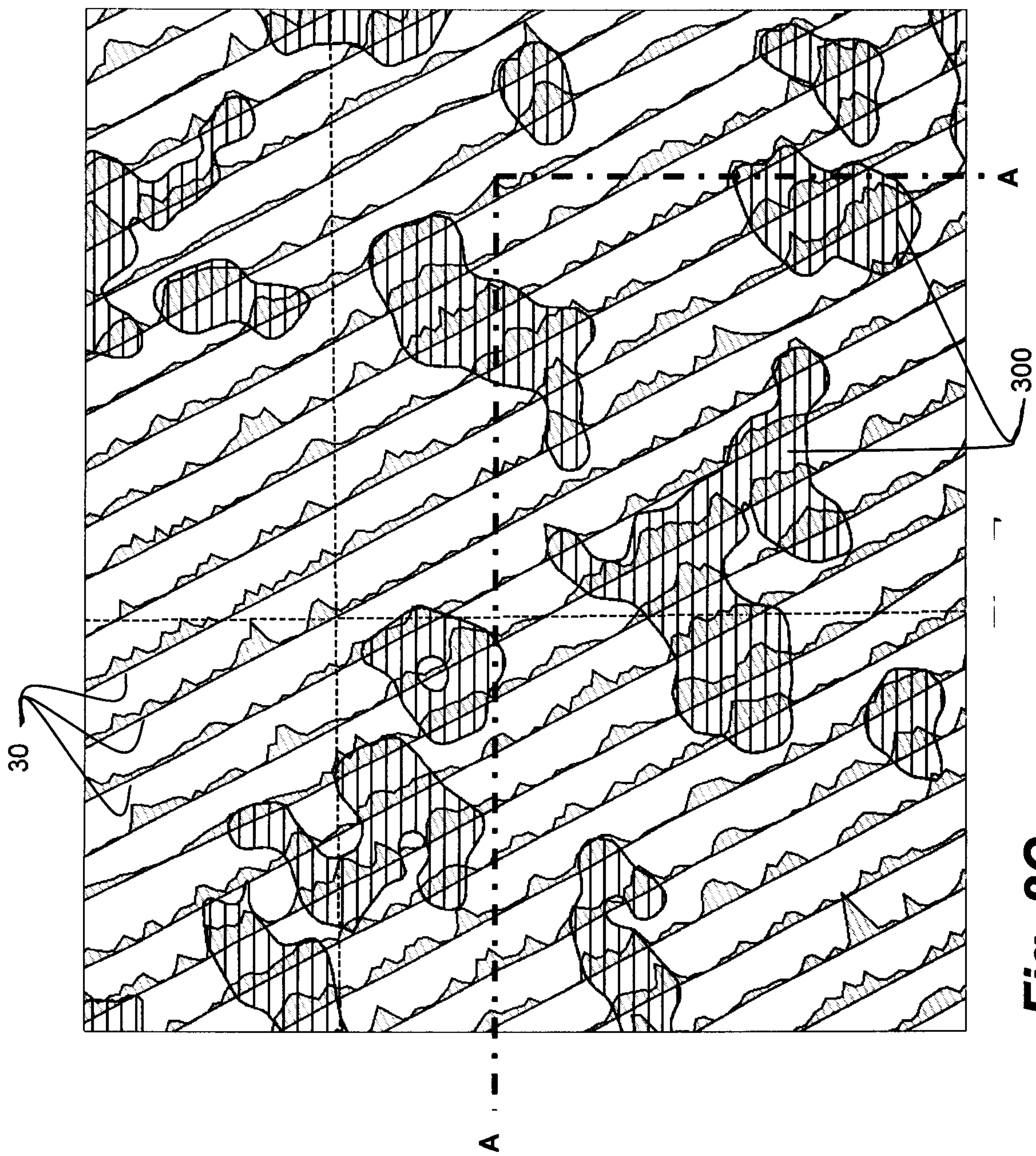


Fig. 8C

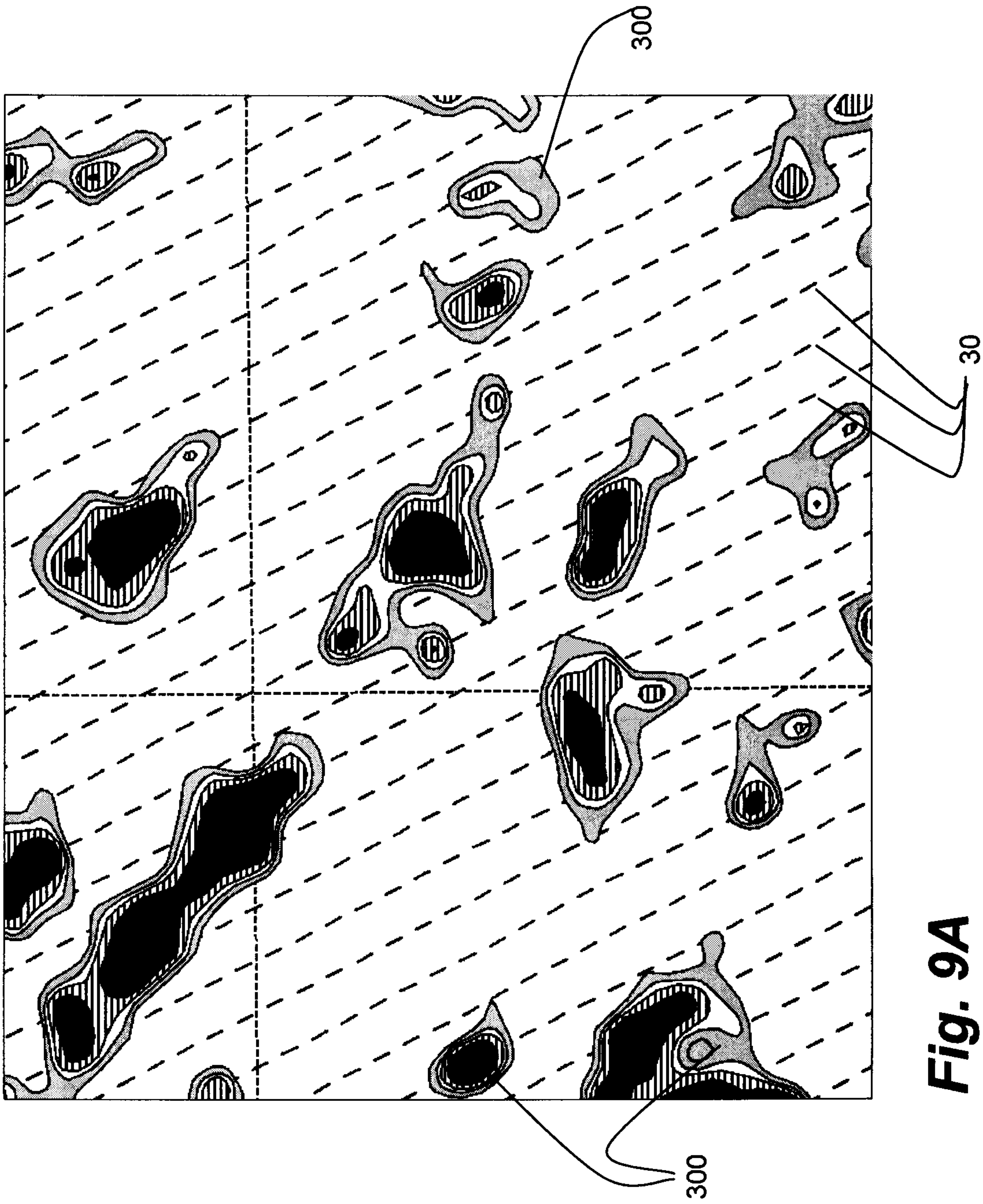


Fig. 9A

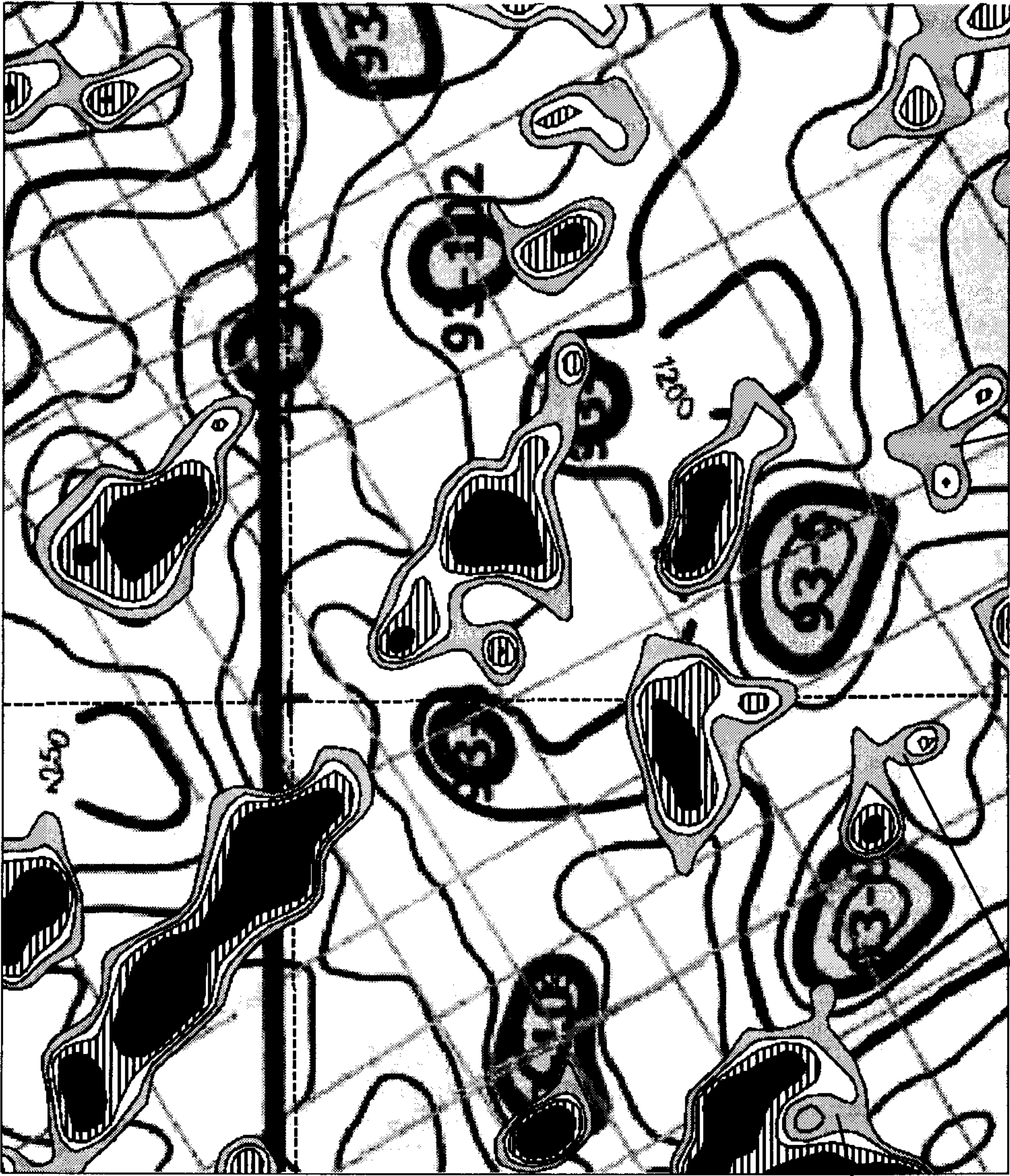


Fig. 9B

300

300

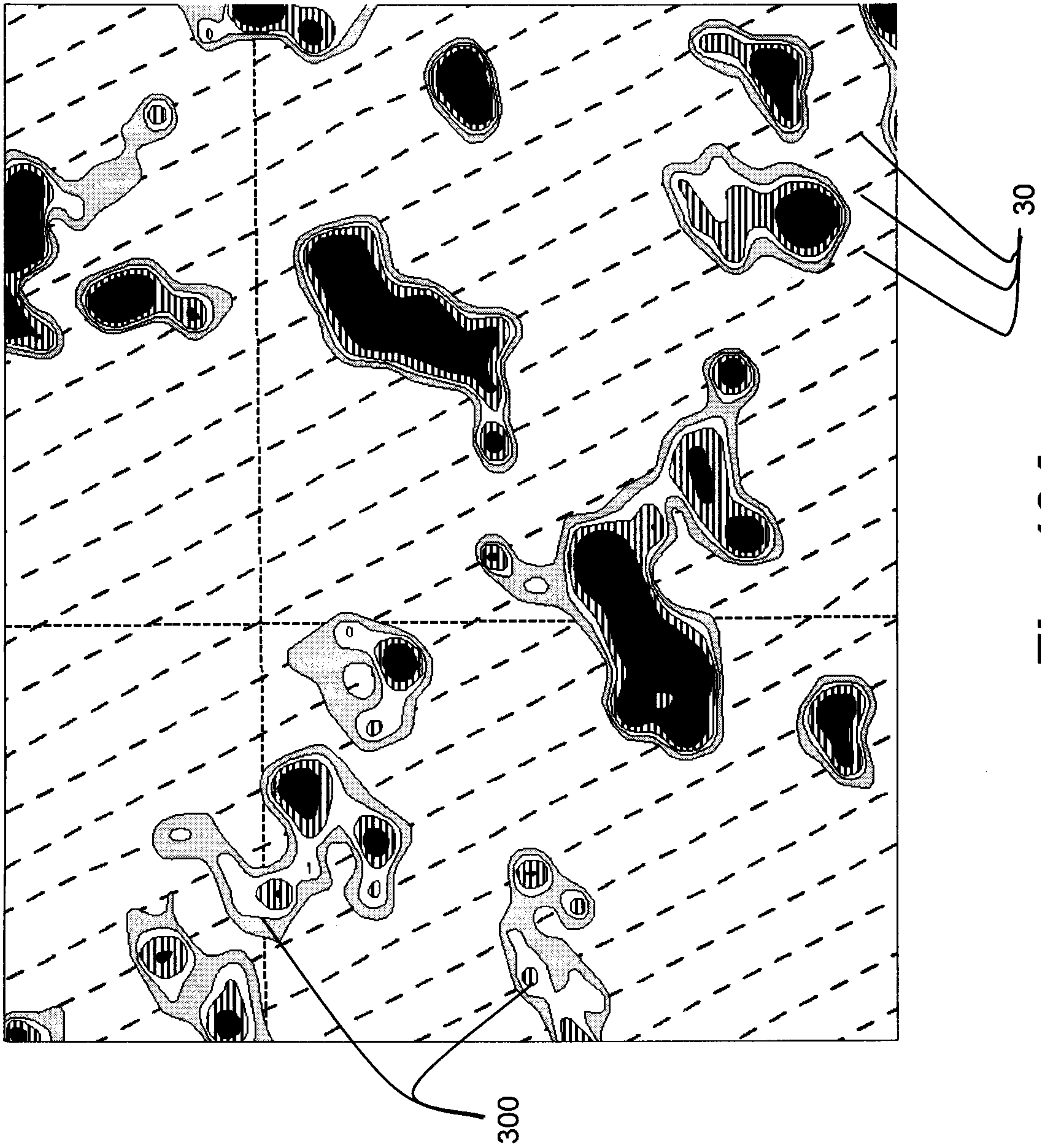


Fig. 10A

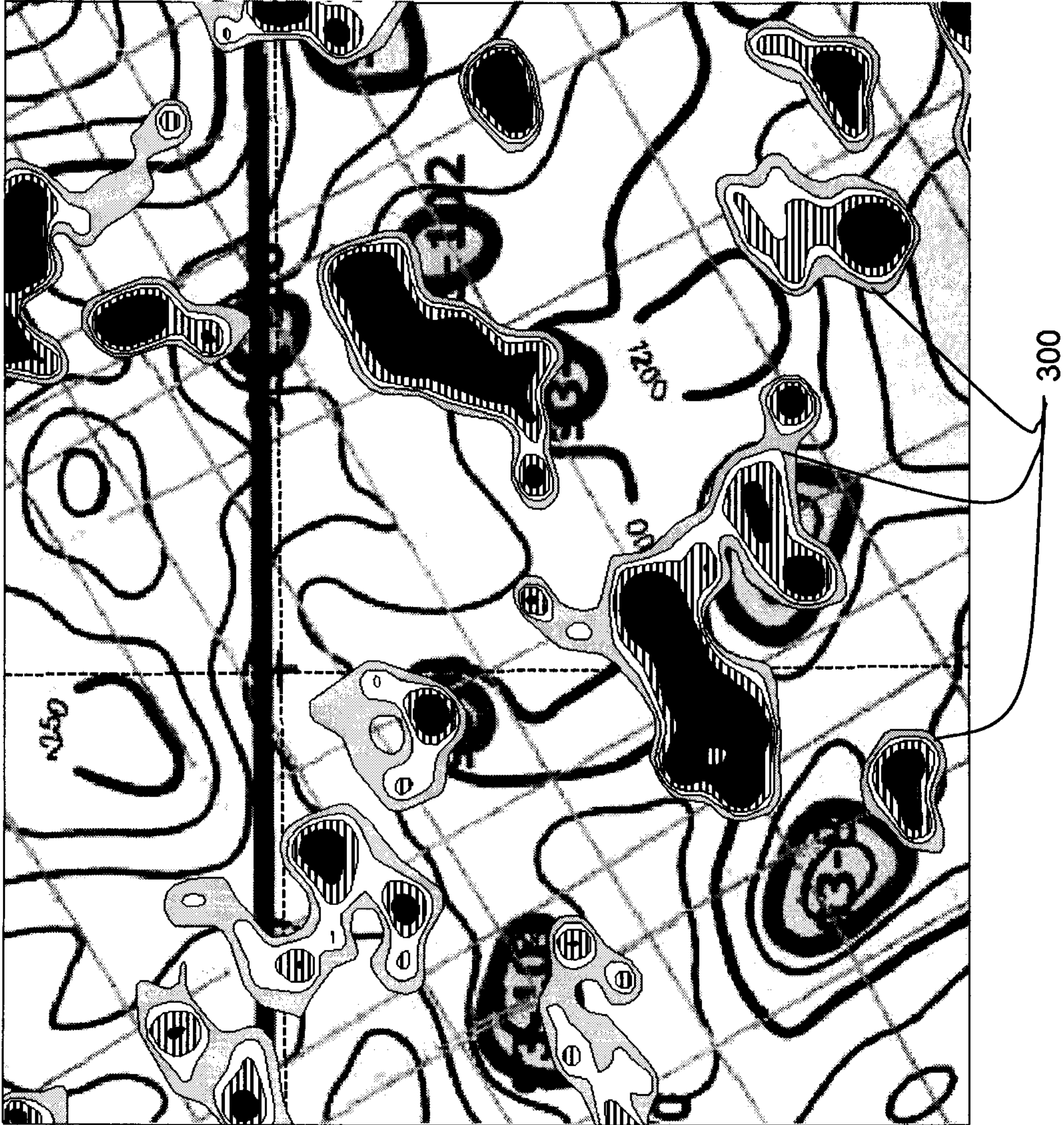


Fig. 10B

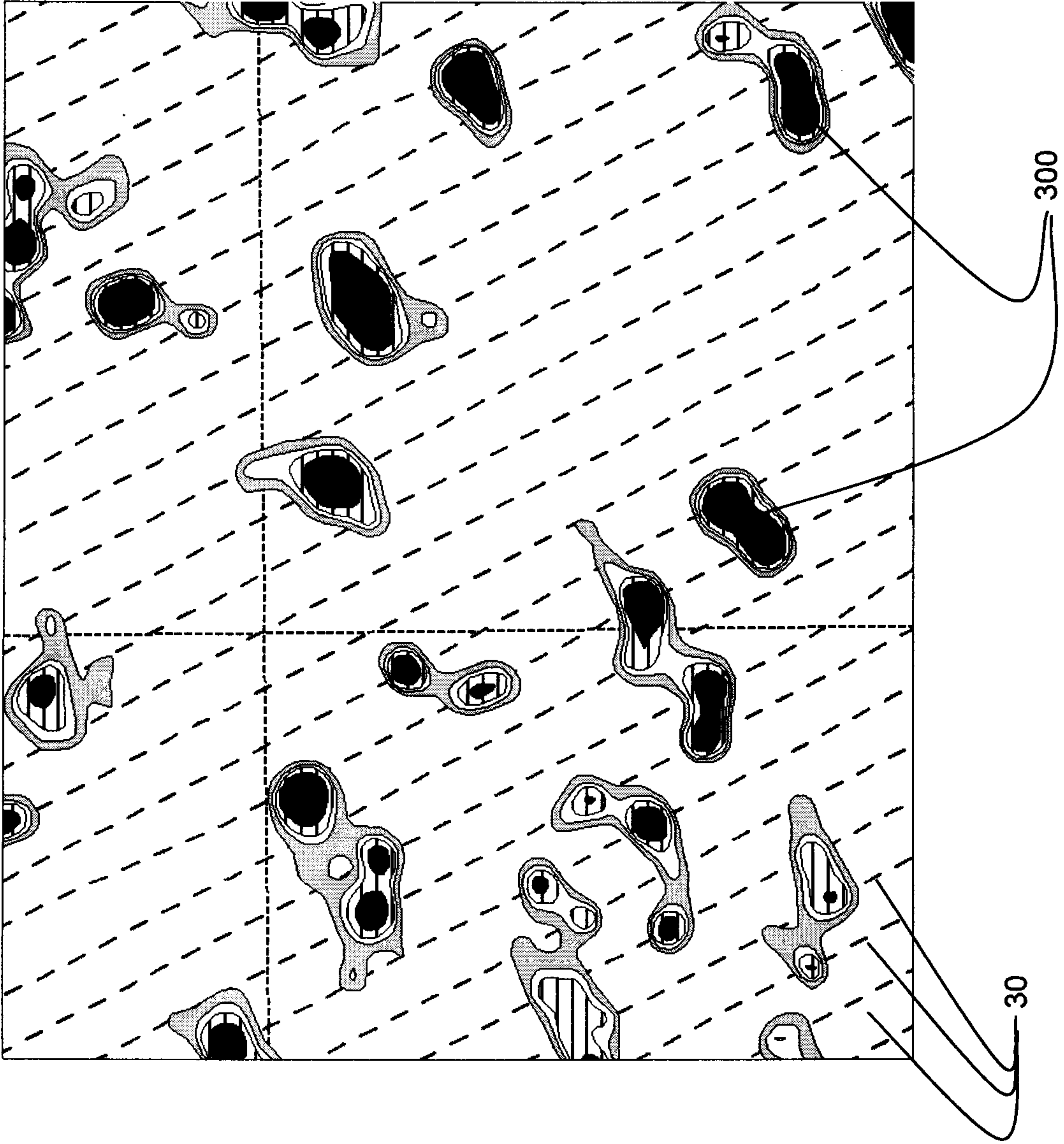


Fig. 11A

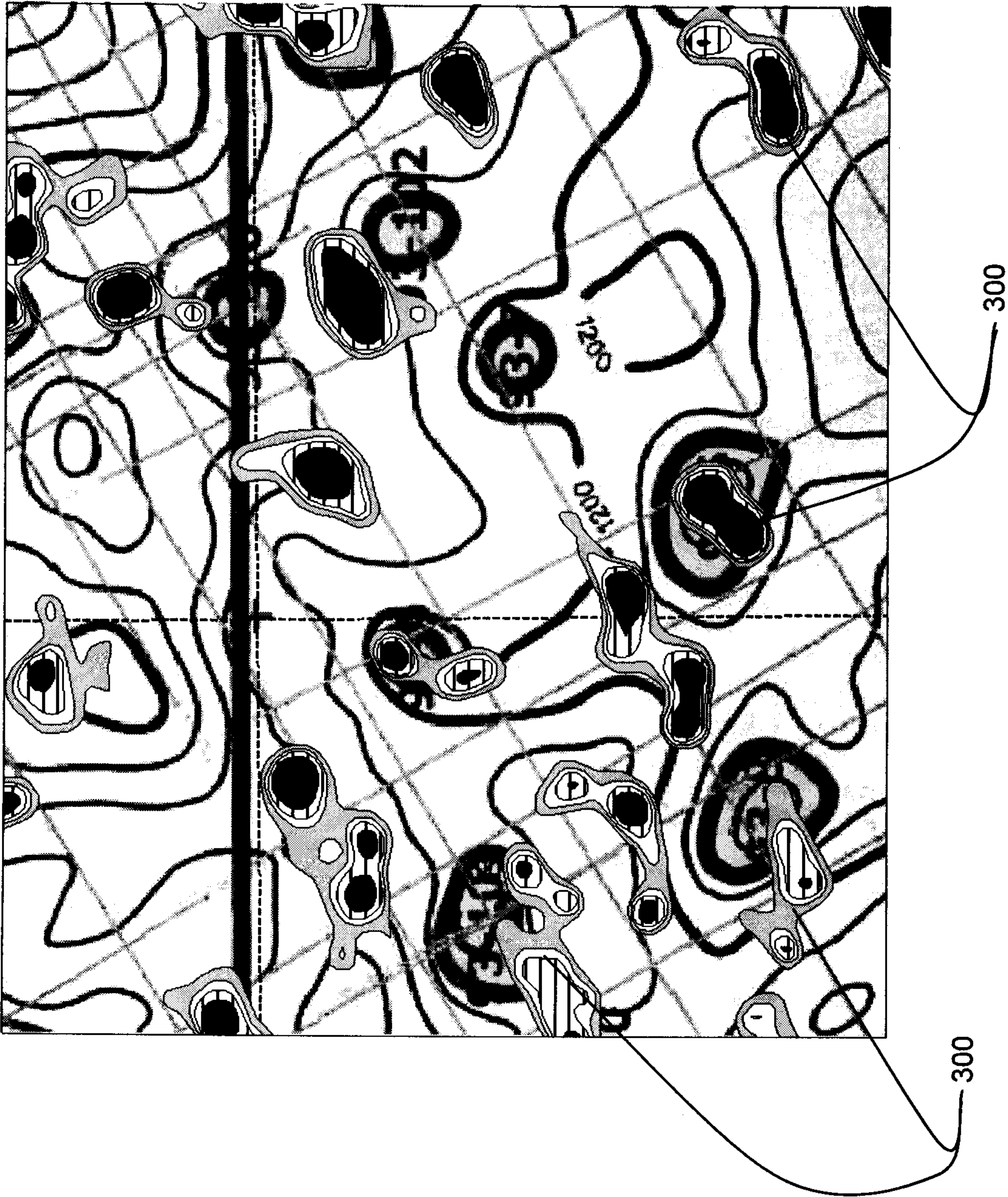


Fig. 11B

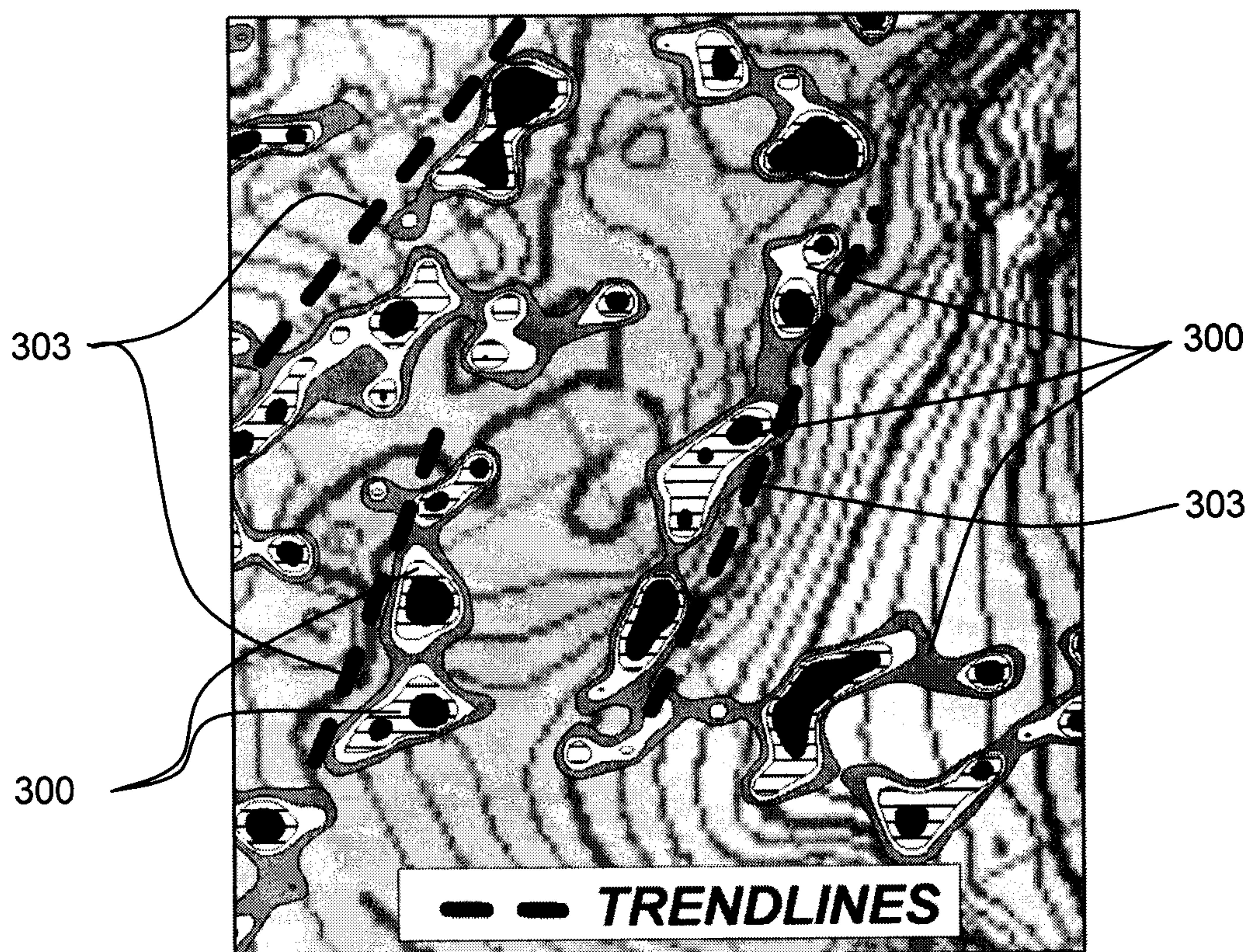


Fig. 12

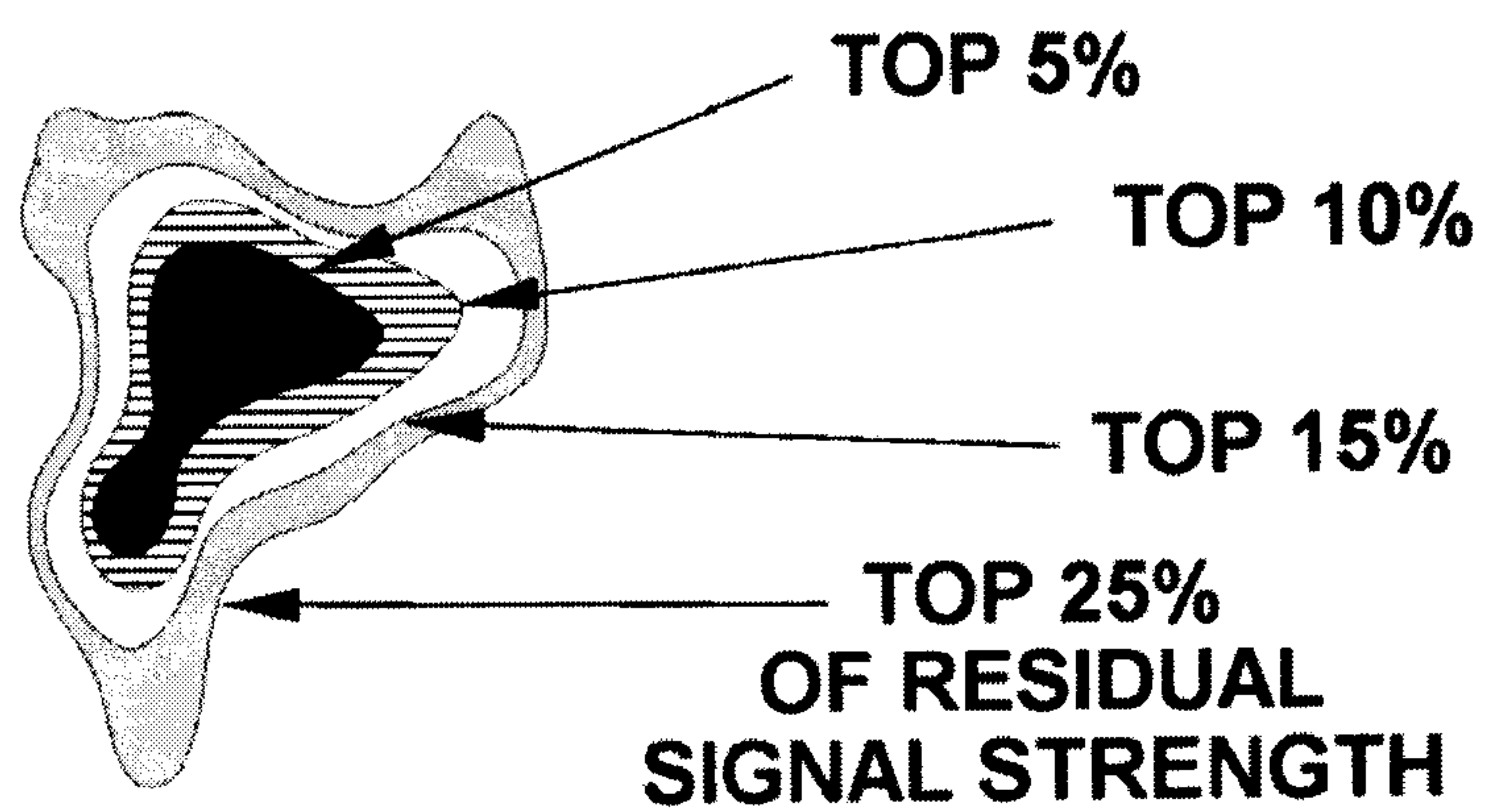


Fig. 13

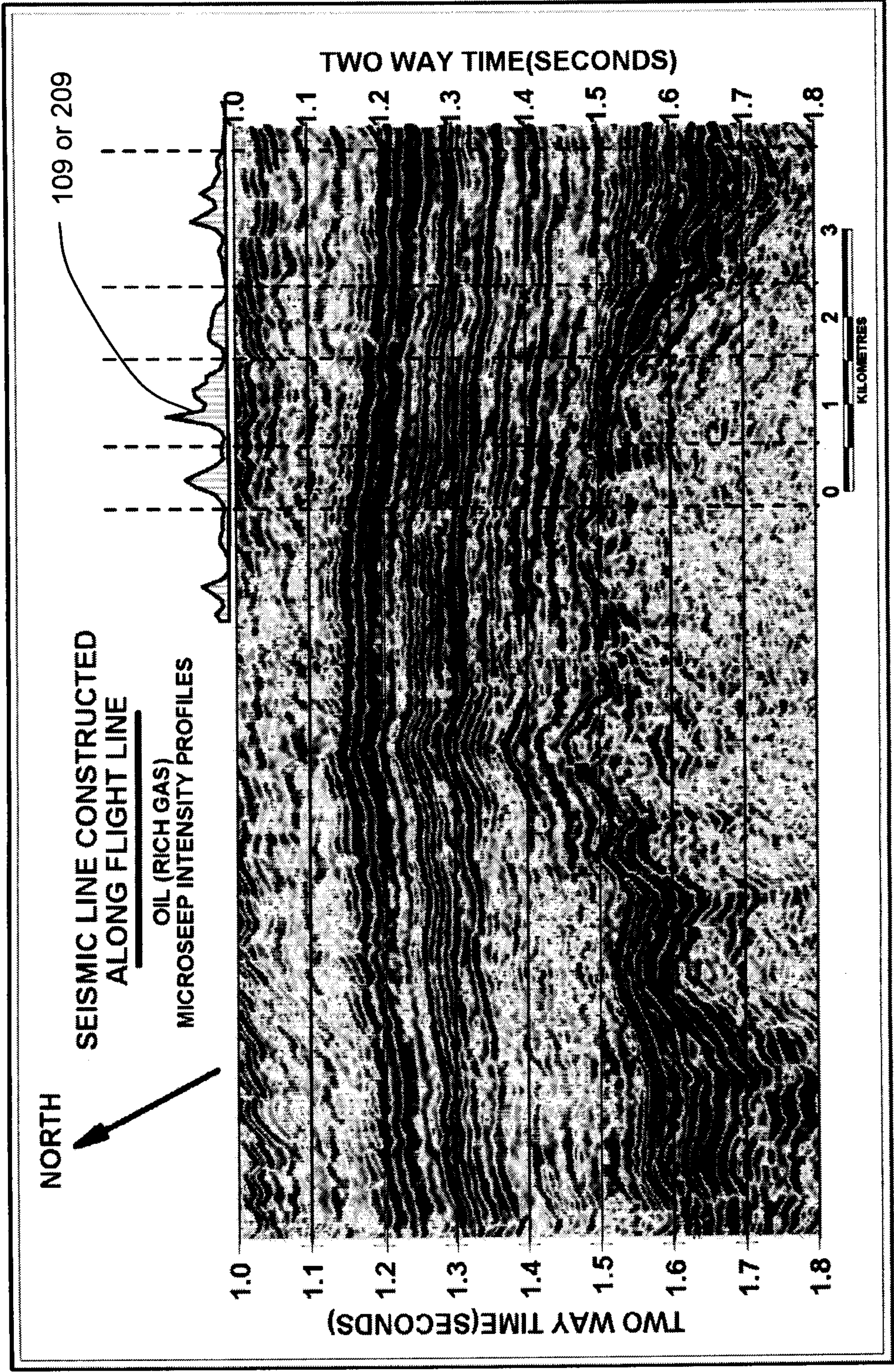


Fig. 14

