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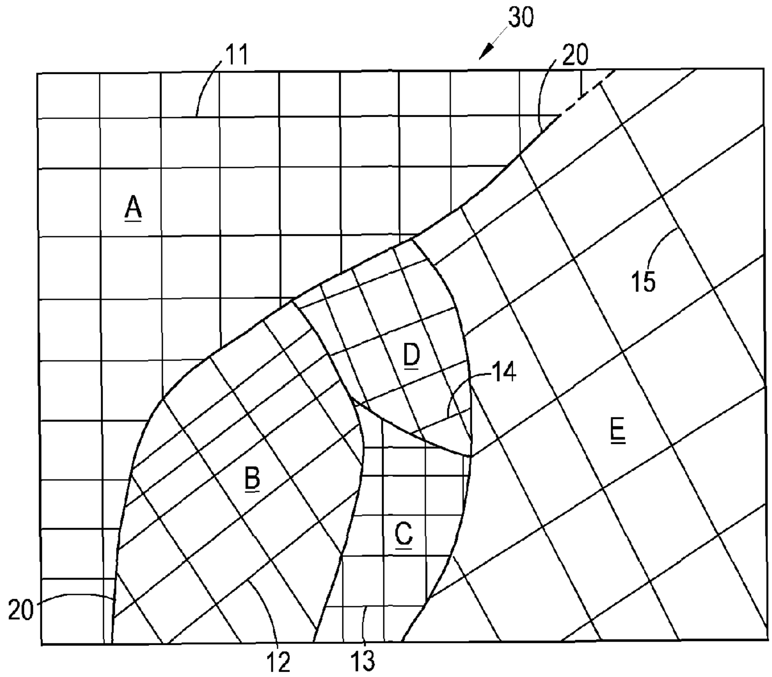

Fig.3

(57) Abstract: The present invention relates to grid models of geological structures. In an embodiment, it relates to forming a grid model of a geological structure by forming a grid, cutting the grid along a surface to form a grid model. In specific examples, the method includes identifying fault blocks and their bounding surfaces and individually forming a grid for each fault block. The grids may then be cut along the bounding surfaces to form block grids which reflect the geometry of the fault block. The individual block grids may then be assembled to form an assembled grid model.

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IMPROVEMENTS RELATING TO GRID MODELS

The present invention relates to grid models, and in particular, but not exclusively, it relates to a method of forming a grid model of a geological structure.

It is useful to be able to model complex physical systems in order to better understand and predict their behaviour. Many natural world systems lend themselves to modelling of this kind. In the earth sciences, geological models are used to understand sub-surface behaviour, for example, to estimate how fluids may flow or how other fields or signals may propagate in the sub-surface, given certain parameters and conditions.

In oil and gas applications particularly, it is useful to predict or simulate fluid flow in a hydrocarbon reservoir. For this purpose, a geological grid model of the reservoir region is typically used, where a geological model is divided into discrete cells. This division into cells facilitates numerical estimation of the fluid flow. In this context a grid relates to a control volume type grid. In such a grid, space is divided into cells (also known as "control volumes") which are closed volumes in space. This is in contrast to a point grid which uses connected nodes (points) in space.

In order to improve accuracy of fluid flow estimates in reservoirs, it is desirable to take account of structural data. For example, it is desirable to include data regarding various discontinuities such as fault surfaces which may impact significantly on fluid flow. In existing reservoir modelling techniques, the manner and extent to which such discontinuities are taken into account differs.

A problem with proposed grid models is that incorporation of such features may result in a significant slow down of the modelling process or may prevent reliable performance and functionality altogether. This may result from trying to satisfy other constraints or conditions of processing the model data and deriving the estimate of fluid flow.

In this specification we refer variously to block units, model blocks, geological blocks and fault blocks. It should be understood that block units, model blocks and geological blocks are all synonymous. A fault is a special case of a boundary surface, and a fault block is therefore a special case of a geological block (or block unit or model block).

The invention provides a method of forming a grid model of a geological structure, and a method of estimating a physical characteristic of a geological region, as set out in the accompanying claims.

There will now be described, by way of example only, embodiments of the invention with reference to the accompanying drawings, in which:

Figure 1 is a plan view of a reservoir region with fault blocks A-E;

Figure 2 is a representation of an initial corner point grid from which a block grid of the fault blocks A-E is formed;

Figure 3 is a plan view of an assembled grid model of the reservoir region of Figure 1, formed from block grids for each fault block A-E;

Figure 4 is a perspective view of two block grids juxtaposed along a boundary fault surface;

Figure 5 is a schematic representation of the formation of a logical or schematic array from the assembled grid model of Figure 3; and

Figure 6 shows a fault block involving both major and minor faults; and

Figure 7 shows a modified method of extrapolating the minor faults shown in Figure 6.

Figure 1 shows a structural model of a reservoir region 1 in which a geological structure of the reservoir region is represented by a number of fault blocks A-E (constituting “model blocks”) delineated by bounding surfaces, including fault surfaces 20. Surface traces of the fault surfaces 20 are seen in Figure 1.

In order to numerically simulate or model a physical behaviour or characteristic in the reservoir region 1, for example to estimate fluid flow, there is formed a grid model of the geological structure. In this case, a method of forming the grid model is followed involving forming block grids individually for each of the fault blocks A-E.

A separate block grid for each fault block is formed, each starting from a separate initial grid 10 as shown in Figure 2. In this way, each block grid is formed from a separate initial grid. The initial grid is firstly defined with a volume selected to encompass the dimensions of the particular fault block to be represented by the block grid. In Figure 2, the initial grid 10 is a simple regular grid in the form of a typical corner point grid, defining columns of cells 10c in multiple rows 10r. A corner point grid uses cells, each with 6 faces, where each cell can be identified by integer coordinates (i,j,k). The corner point grid is stratigraphically conforming, and thus not fully orthogonal in 3D.

The cells are defined with appropriate dimensions in three orthogonal directions, thus, together with a selected subdivision of the stratigraphic layers, defining volume cells and an overall 3D volume of the grid suitable for the fault block. By defining cell dimensions, a suitable grid resolution is set, for example to take appropriate account of important features of the fault block and to facilitate speed of processing grid cells for estimating the physical characteristics to be modelled. In addition, the initial grid 10 for each fault block may be oriented into a particular orientation to facilitate processing speed and reliability. Typically, the orientation and resolution of the grids are chosen to optimise fluid simulation in the block to which it is associated.

In general, the resolution and orientation of the initial grids is set differently for different fault blocks. For example, one initial grid may have small cell dimensions and a fine resolution to model a thin geological feature of the reservoir present in the particular fault block concerned. If such a layer is not present in the other fault blocks, the modelling grid for such other fault blocks might have a coarser grid resolution.

It will be noted that the initial grid can also be of any type, and is not limited to being of the corner point grid type illustrated in Figure 2. For example, the grid could be a hexahedral grid. The rows and columns of the grid in Figure 2 have a regular shape and dimensions, but it will be noted that in other cases, different rows and columns may have different widths or heights within the same initial grid.

In this way, the formation of the initial grids is carried out independently for each fault block and the grid resolution, cell dimensions and orientation of the initial grid 10 is determined in isolation without incorporation of the bounding surfaces.

The next step is to cut an initial grid 10 for a given fault block along the fault surfaces 20 for the fault block, once the initial grid has been formed as described above. In the example of Figure 2, a portion 20p of a fault surface 20 is specified, and the corner point grid 10 is then cut along the portion 20p where the fault surface intersects with the grid. As a result, a portion 10b of grid 10 outside the fault surface 20 is removed, whilst a main portion 10a of the initial grid 10 is retained to provide a basis for the block grid. The initial grid may then be cut by further portions of fault surfaces (not shown), which may have different attitudes, in order to shape the grid into the required form and obtain a final block grid that closely follows the overall geometry of the fault block.

In practice, the cutting step involves removing or omitting cells outside the boundary surface of the block, and modifying dimensions of cells which are cut by the surface. Thus, the cells which are cut are typically irregular in form, and have boundary-facing edges and points of intersection with the fault surface that lie in the plane of the bounding fault surface of the structural model.

Typically, the orientation and resolution of the initial simple regular grid may be selected to ensure that it is favourably or optimally built for data processing, for example to simulate fluid in the resulting block grid.

The optimum form of the block grid for flow simulation is typically to have a regular, k-orthogonal grid everywhere except along block boundaries. In addition, the grid resolution is varied and set (in the formation of the initial grid) according to geological complexity and/or heterogeneity. The grid orientation may be varied and set according to a main flow direction.

The steps described above are performed independently and individually for each initial grid and fault block A-E.

In this way, individual block grids 11-15 are created and built separately for each fault block, each having an outline shape that follows exactly the geometry of the respective fault block of the structural model. The orientation and resolution of the block grid for one block will be dependent on that of the corresponding initial grid from which it was formed, and in general therefore will be independent of the grids formed and the grid properties chosen for other blocks.

The individual block grids 11,12,13,14 and 15 are then assembled together into an assembled or joint grid model 30 of the overall structure, as seen in Figure 3. The block grids have different rotational orientations and cell sizes, corresponding to the selected dimensions of the initial grid for each fault block, but are aligned against each other along bounding fault surfaces 20.

In Figure 4, the nature of the assembled grid 30 is shown in more detail. Figure 4 shows two modelling grids 40, 50, for example representing fault blocks A and B, juxtaposed against each other along the fault surface 20 common to these fault blocks (along which both of the initial grids for these two fault blocks were cut). As can be seen, the cells adjacent to the common fault surface 20, for example cells 40a, 50a, have an irregular form as a result of being cut by the fault surface 20. If any of these irregular cells are very small, they are typically merged with neighbouring cells. The cells of grid 40 adjacent to the fault surface (which may be planar or curved) have intersection points and edges that lie substantially in the fault surface. These edges can be considered to define a facing surface 40f of the grid which lies tightly against or in contact with a corresponding facing surface 50f of the adjacent grid 50, without any gap between the facing surfaces 40f, 50f.

The result is a joint or assembled model grid that very accurately represents the structural geology of the reservoir, even when the geological structures are complex.

The formation of an assembled or joint grid model in this way, is particular advantageous in that selected block grids or portions of the structural model may be updated or changed, for example, to incorporate additional geological features, without affecting other parts or other grid blocks of the model. For example, one block or block grid can be modified without interfering with the rest of the grid. It also eliminates manual editing of the grid.

Once constructed following the steps above, the joint/assembled grid model 30 can be used to simulate reservoir fluid flow. In the case of fluid flow, fluid transmissibility across cells needs to be determined, including between cells of adjacent block grids across their common bounding fault surface. This may require taking into account possible sealing properties of the boundaries themselves, e.g., the sealing effect of fault surfaces. In order to do this, cells 40a, 50a that lie against the common fault surface 20 of adjacent block grids 40, 50 are linked to each other mathematically, and an area of contact of the facing surfaces 40f, 50f is determined.

The assembled grid 30 is transformed or mapped into a logical grid or logical array 60 for processing and performing the simulation calculations as can be seen with further reference to Figure 5. This may be done for example by splicing the individual block grids using non-neighbour connections into an i,j,k logical grid or array 60.

Within each block unit, cells are labelled by integer coordinates (i,j,k). Within each block unit each cell has 6 physical neighbours, and physical neighbours are also neighbours in the integer coordinates.

Cells in the logical grid 60 are also be labelled by integer coordinates (I,J,K) (the term “ijk logical grid” refers to this labelling), and each block-unit grid is mapped into non-overlapping parts of this logical grid in such a way that the 6 physical neighbours (within a block unit) are neighbours in the logical grid integer coordinates (by a translation and/or rotation, example I = i + 42 , J = j + 13 , K = k + 2).

- A cell in one block unit that is physical neighbour with a cell in another block unit (sharing a face at a block unit boundary), may not be neighbours with the same cell in the integer coordinates (I,J,K) of the logical grid 60. Flow calculation properties, such as fluid transmissibility will be calculated for the physical connection between these cells, and these properties constitute "non-neighbour connections" in the logical grid.

Physical parameters and data may then be assigned to the cells of the logical array for processing, e.g., to calculate a numerical estimate of a physical property of the reservoir region, such as fluid flow. In the case of fluid flow, fluid transmissibility and volume estimations can then be output and exported to a control volume simulator package.

The logical array 60 may include sub-arrays 61, 62, 63, 64, 65 associated with respective grid blocks 11, 12, 13, 14, 15. These sub-arrays may be arranged within overall logical array 60 to optimise one or more of the dimensions 60x, 60y to facilitate processing.

With reference to Figures 6 and 7, we next describe a further embodiment of the method described above.

In the discussion which follows we use the expression "block unit" (sometimes shortened to "BU") to refer to a fault block, such as fault blocks A-E referred to above.

We also use "joined block unit grid" (sometimes shortened to "JBU grid") to refer to a "joined fault block grid", such as the joint or assembled grid 30 referred to above. These terms are more general and reflect the reality of the grid concept.

The grid methodology as described up to now assumes that all faults (or unconformities) represent a block unit boundary. Also, in the prior art it is normal to treat all faults equally. However, when many faults are presents, including smaller faults, we can conveniently divide the faults into two categories: ie major and minor faults.

We use major faults to form block units; these faults therefore represent block unit boundaries.

We use minor faults to define internal faults within a block unit. These minor faults do not themselves form block units, and they do not represent boundaries of blocks. Instead they are internal faults, which lie within the block units defined by the major faults. The minor faults are therefore herein also referred to as intra-block faults.

We next describe how we include intra-block faults into a JBU-grid.

Figure 6 shows an example of the method which involves a block unit A, bounded by major faults F1 - F4. Block unit A contains two minor faults f1 and f2.

We first extrapolate the intra-BU faults f1 and f2, both laterally and vertically, up to the boundaries of BU A (whose lateral boundaries are the four major faults F1, F2, F3 and F4). The extrapolations are shown by dotted lines in Figure 6. The fault throw is defined as null along the extrapolated parts of the minor faults.

As shown in Figure 6, this divides the BU A into three sub-block units A1, A2 and A3. A hierarchy of block units can thus be introduced.

We next build grids for the three sub block units A1 - A3 according to the JBU grid method described earlier, using three initial grids being exactly identical in the XY-plan (see figure 6, grid G).

We next merge the three sub-BU grids into one single BU grid. The goal here is to avoid unnecessary misshaped cells (for numerical reasons when running flow simulations). Indeed, the cells along the extrapolated parts of the minor faults (dotted lines in Figure 6) are split in the grid building process. However they do not need to be split since in reality the faults do not exist in the extrapolated parts.

The merging process we use is as follows.

We check all the cells adjacent to the surfaces of the minor faults f1, f2.

If the fault throw is not null we just continue scanning.

If the fault throw is null, then we modify the extrapolated fault surface so that it follows the nearest regular grid cell surface. This is shown by lines 70 in Figure 7, which follow the grid cell boundaries.

As a result the boundaries of the sub-BU follow the regular grid pattern everywhere where the minor faults do not actually exist. This gives a continuous and regular grid throughout the whole BU A except exactly where the minor faults f1, f2 exist.

Various modifications may be made within the scope of the invention herein described.

CLAIMS

1. A method of forming a grid model of a geological structure, the method comprising the steps of:
   a) forming a first initial grid for modelling a first geological block of the structure;
   b) cutting the first initial grid to form a first block grid;
   c) forming a second initial grid for modelling a second, different geological block of the structure;
   d) cutting the second initial grid to form a second block grid; and
   e) assembling the first and second block grids to form an assembled grid model of the geological structure.

2. A method as claimed in claim 1, including the steps of:
   - providing a structural model of the geological structure;
   - identifying first and second model blocks of the structural model in which the model blocks represent said first and second geological blocks; and
   - identifying bounding surfaces of the first and second model blocks.

3. A method as claimed in claim 2, wherein step b) is performed by cutting the first initial grid along a first bounding surface to form the first block grid and step d) is performed by cutting the second initial grid along a second bounding surface to form the second block grid.

4. A method as claimed in claim 3, wherein the first and second bounding surfaces are the same surface such that cutting the first and second initial grids along the first and second bounding surfaces defines complementary outer surfaces of the first and second block grids, and step e) includes arranging the first and second block grids against each other along the complementary outer surfaces.

5. A method as claimed in any one of claims 2 to 4, wherein the steps of cutting the first and second initial grids along the first and second bounding surfaces includes cutting the first and second initial grids along each of their respectively identified bounding surfaces to form the first and second block grids.

6. A method as claimed in any one of claims 3 to 5, wherein the steps of cutting the initial grids include removing cells outside the bounding surfaces, and forming irregular cells adjacent the bounding surfaces, which irregular cells define edge surfaces that lie substantially along outer surfaces of the block grids.

7. A method as claimed in any one of claims 2 to 6, wherein the first and second block grids define outer surfaces which follow the geometry of the first and second model blocks.

8. A method as claimed in any one of the preceding claims, wherein steps a) and b) are carried out separately from steps c) and d).

9. A method as claimed in any one of the preceding claims, wherein step a) is carried out before step b) and step c) is carried out before step d).

10. A method as claimed in any one of the preceding claims, wherein forming the first and second initial grids includes selecting a resolution of each initial grid individually.

11. A method as claimed in claim 10, wherein selecting a resolution includes defining grid cells and selecting dimensions of the grid cells.

12. A method as claimed in any one of the preceding claims, wherein forming the first and second initial grids includes selecting an orientation of each initial grid separately.

13. A method as claimed in any one of the preceding claims, including the step forming a logical array by converting the assembled grid model into a logical array.

14. A method as claimed in claim 13, wherein the steps of forming a logical array include forming first and second logical sub-arrays associated with said first and second block grids respectively, and arranging the logical sub-arrays for processing.

15. A method of estimating a physical characteristic of a geological region, the method including the steps of:
    a. forming a grid model according to any one of the preceding claims, the grid model comprising block grids each having a plurality of grid cells and grid cell faces defining geological model parameters; and
    b. estimating said physical characteristic based on the model parameters.

16. A method as claimed in claim 15, including the steps of arranging the geological parameters in a logical array and processing data of the array to derive a physical response.

17. A method as claimed in any preceding claim, which further comprises:
    dividing faults in said geological structure into major and minor faults;
    defining at least said first geological block as a region bounded by major faults;
    identifying at least one intra-block fault, being a minor fault within said first geological block;
    extrapolating said intra-block fault to a boundary of said first geological block, if it does not already intersect with said boundary, so that said intra-block fault divides said first geological block into at least two sub block units;

building a sub block unit grid for each of said sub block units, the sub block grids being formed from initial grids which have a common X-Y plan; and merging said sub block unit grids to form a single block unit grid for said first geological block.

18. A method as claimed in claim 17, wherein said step of extrapolating said at least one intra-block unit fault includes extrapolating said at least one intra-block unit fault along the boundaries of cells within at least one of said sub block unit grids.

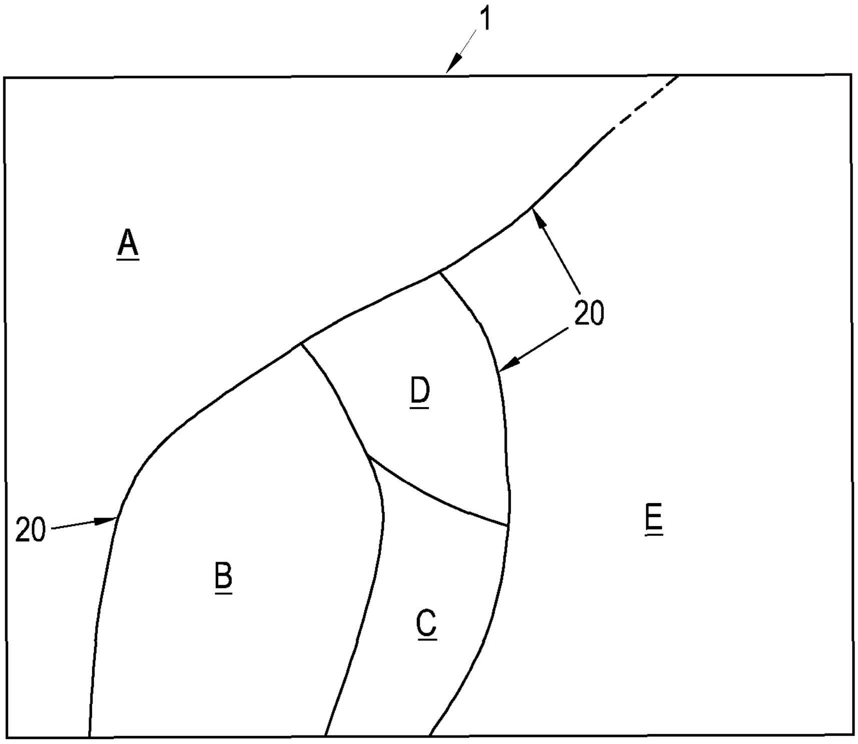

Fig.1

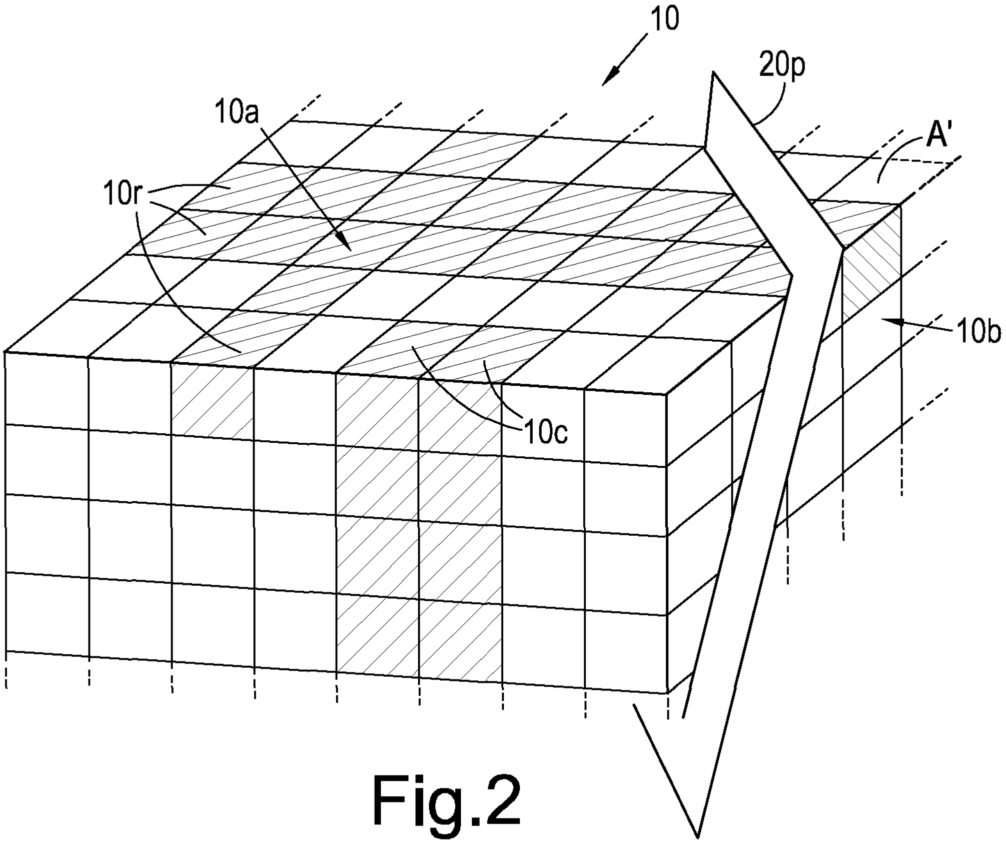

Fig.2

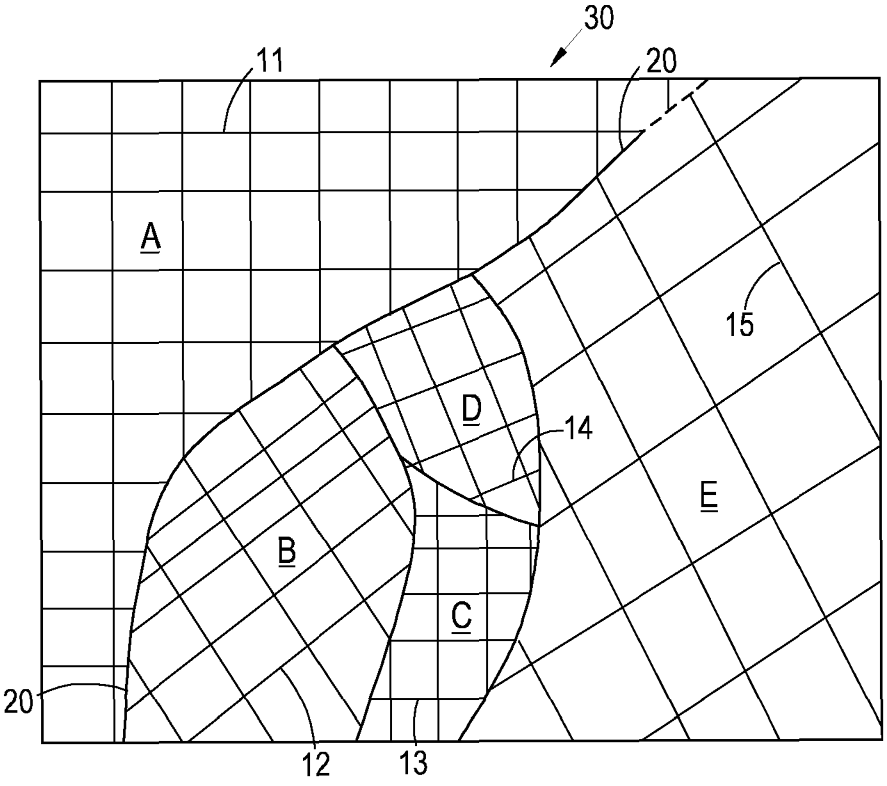
30
11
20
A
15
D
14
B
E
C
20
12
13

Fig.3

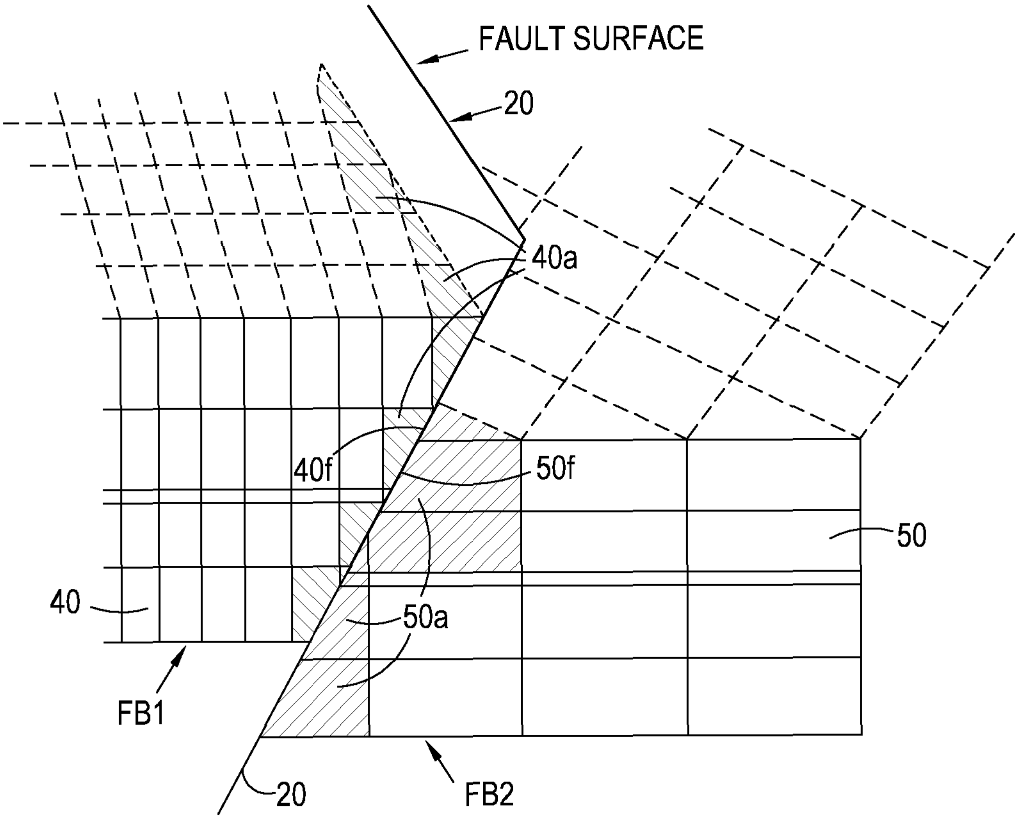
FAULT SURFACE
20
40a
40f
50f
50
40
50a
FB1
20
FB2

Fig.4

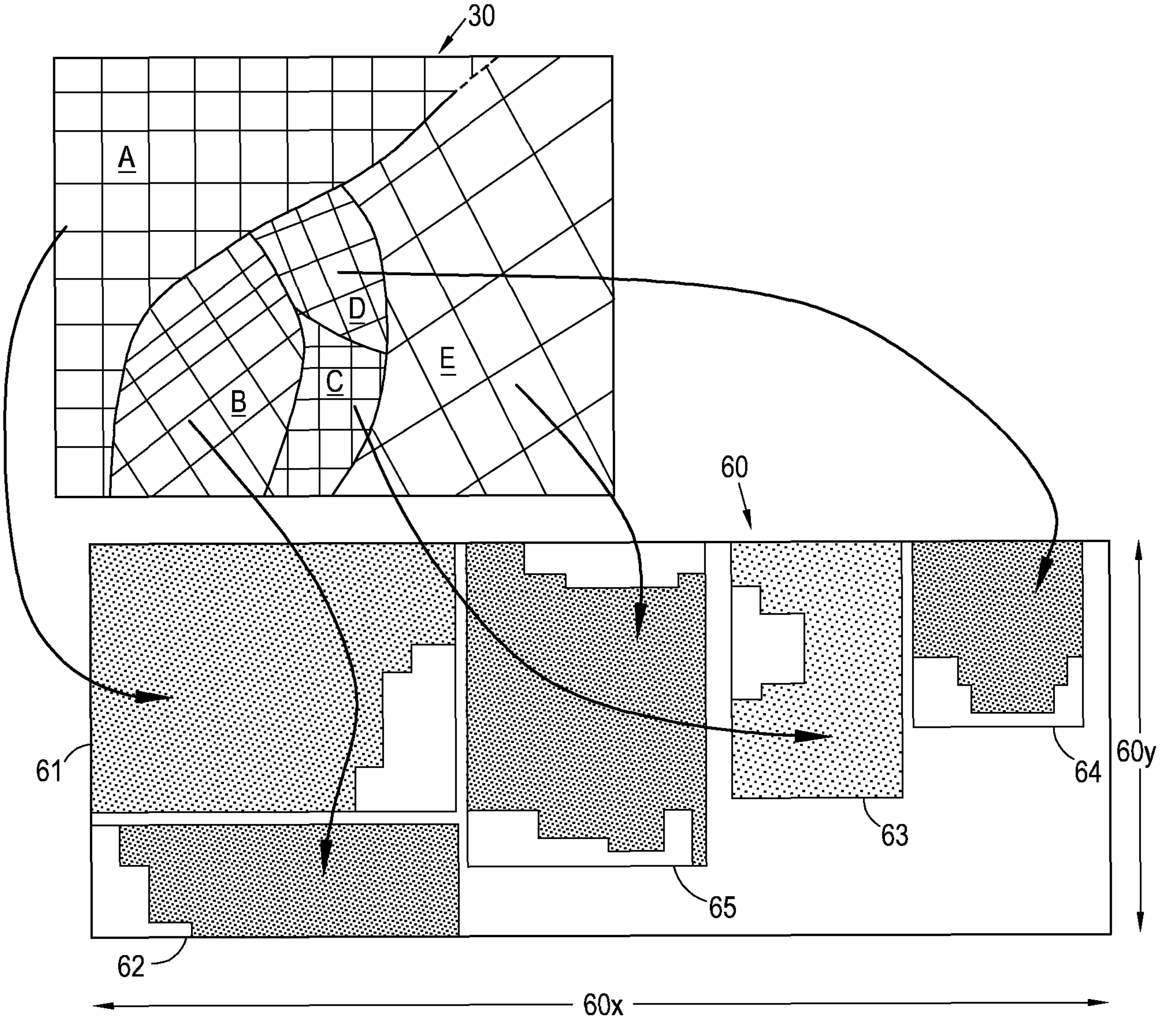

Fig.5

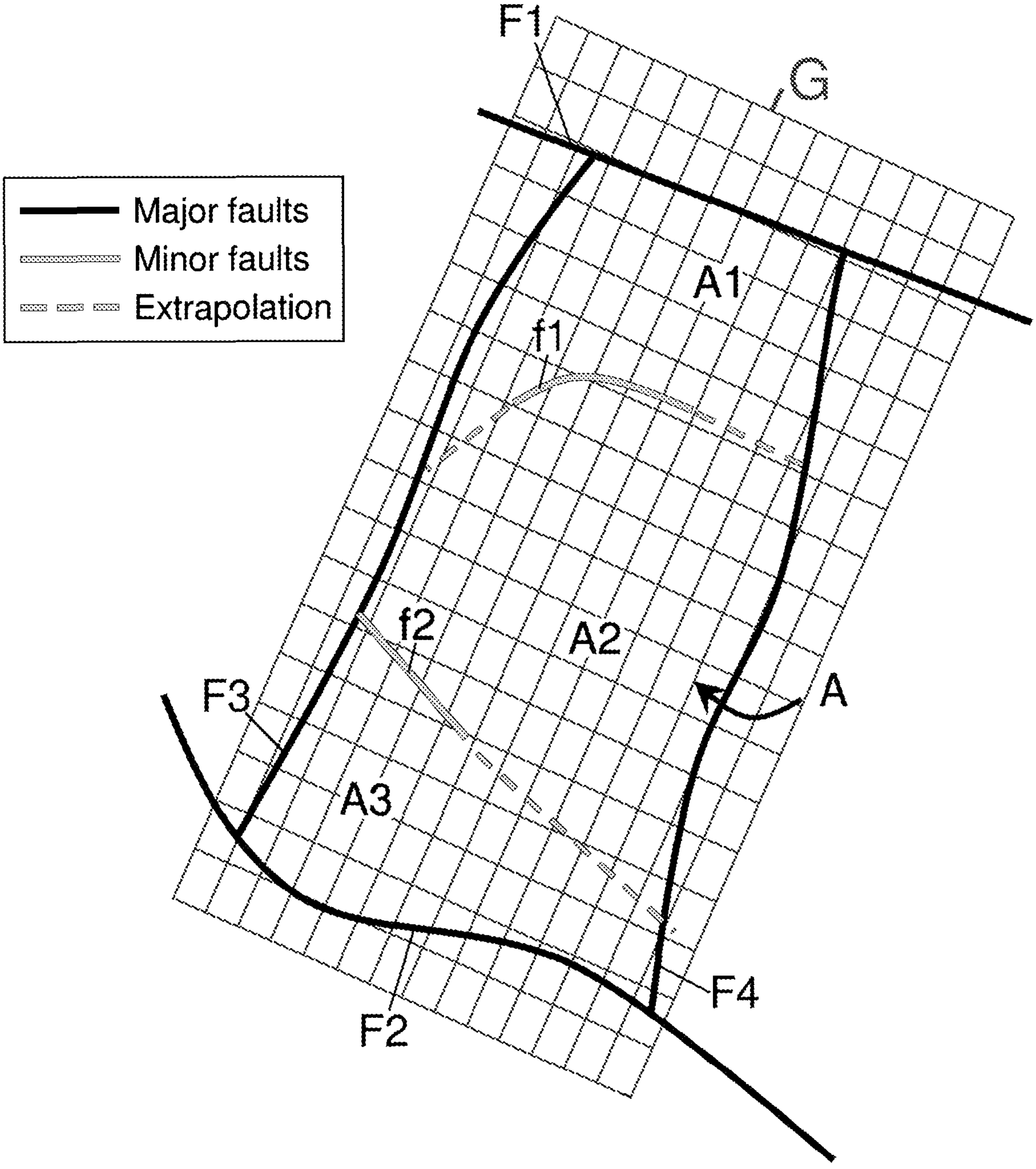
F1
G
Major faults
Minor faults
Extrapolation
A1
f1
f2
A2
A
F3
A3
F4
F2

Fig.6

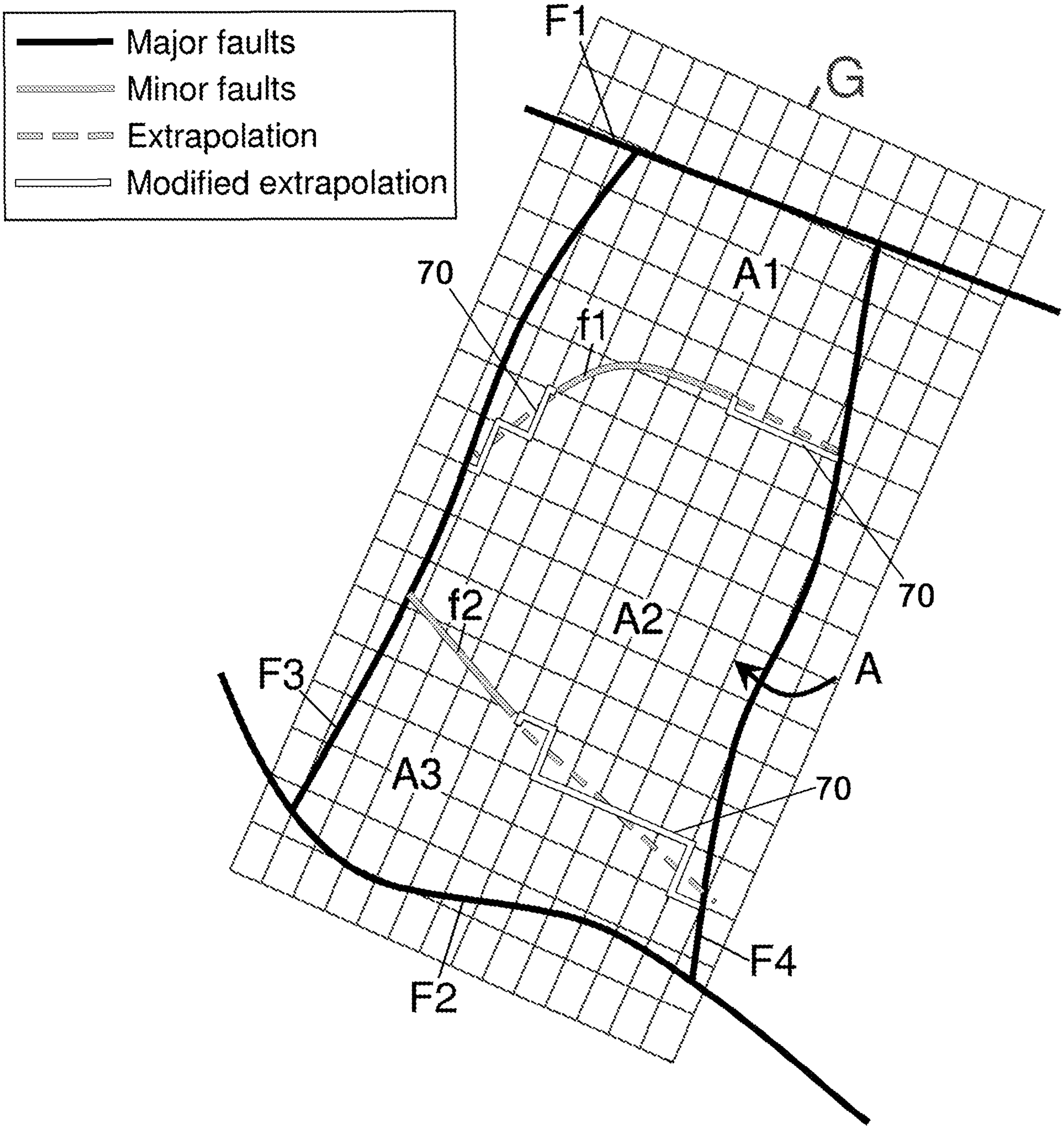
Major faults
Minor faults
Extrapolation
Modified extrapolation
F1
G
A1
70
f1
70
f2
A2
A
F3
A3
70
F4
F2

Fig.7