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(54) METHOD AND SYSTEM FOR DEVELOPMENT OF NATURALLY FRACTURED FORMATIONS

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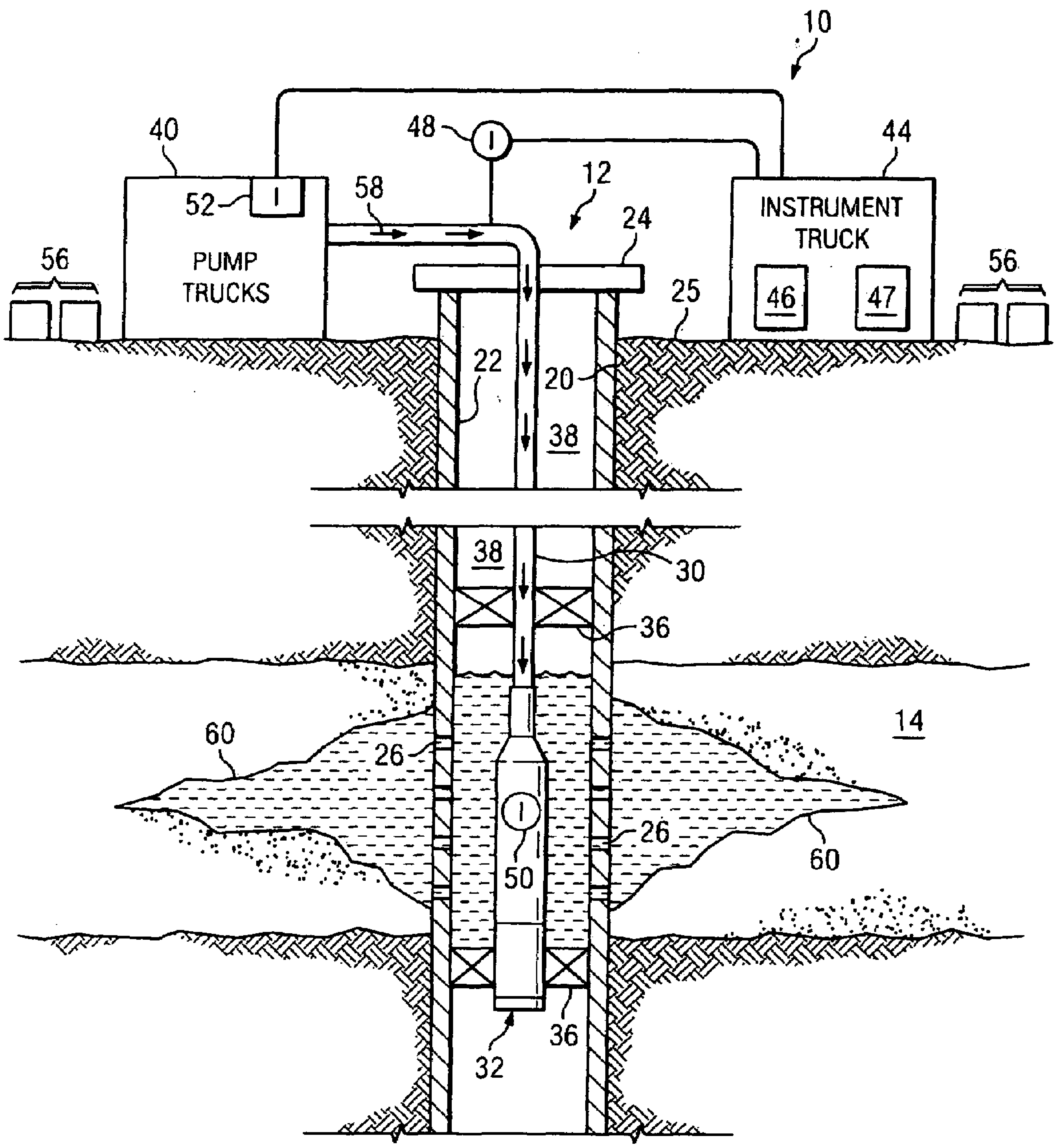
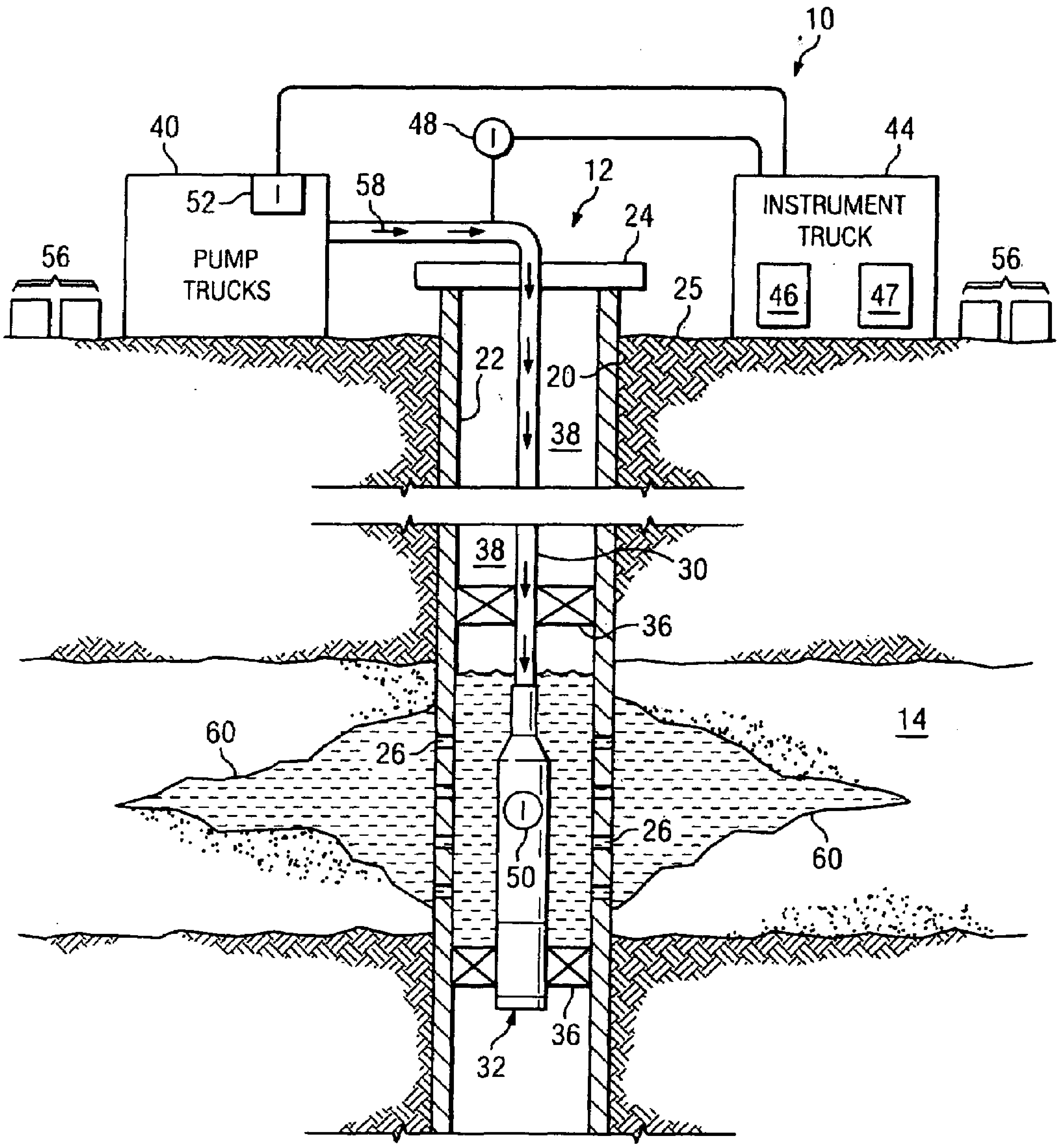
(57) ABSTRACT

A method and system for development of a naturally fractured formation may include generating a fracture model from a fracture treatment of a well in the naturally fractured formation. The fracture model may account for natural fractures in the naturally fractured formation. The fracture model may include the fracture volume of the fracture generated by the fracture treatment. Well spacing and fracture stimulation design for one or more wells in the naturally fractured formation may be determined based on the fracture model.

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40
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PUMP
TRUCKS
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38
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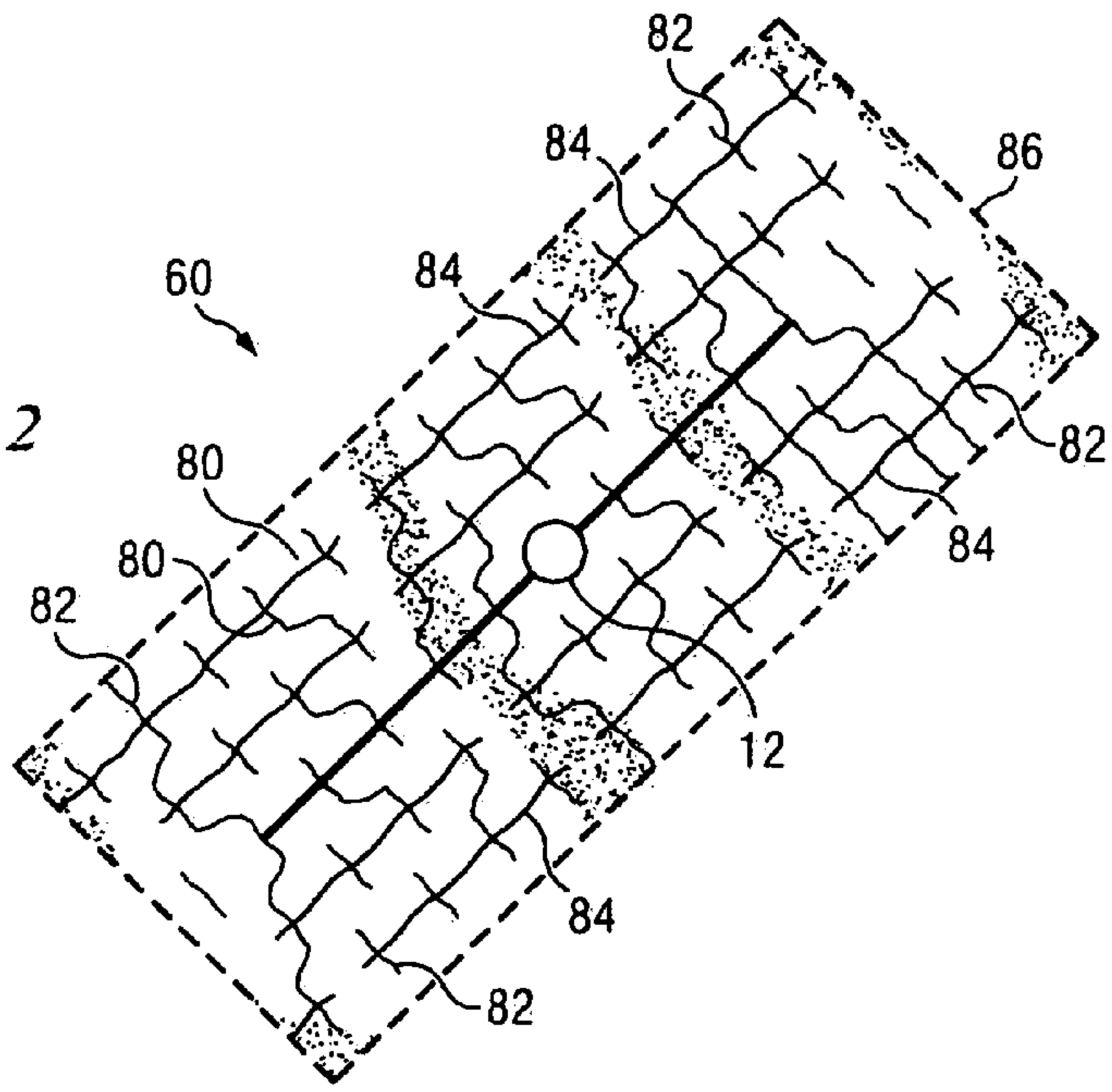
60
50
36
32

FIG. 1

FIG. 2


60
80
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84
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12

FIG. 3

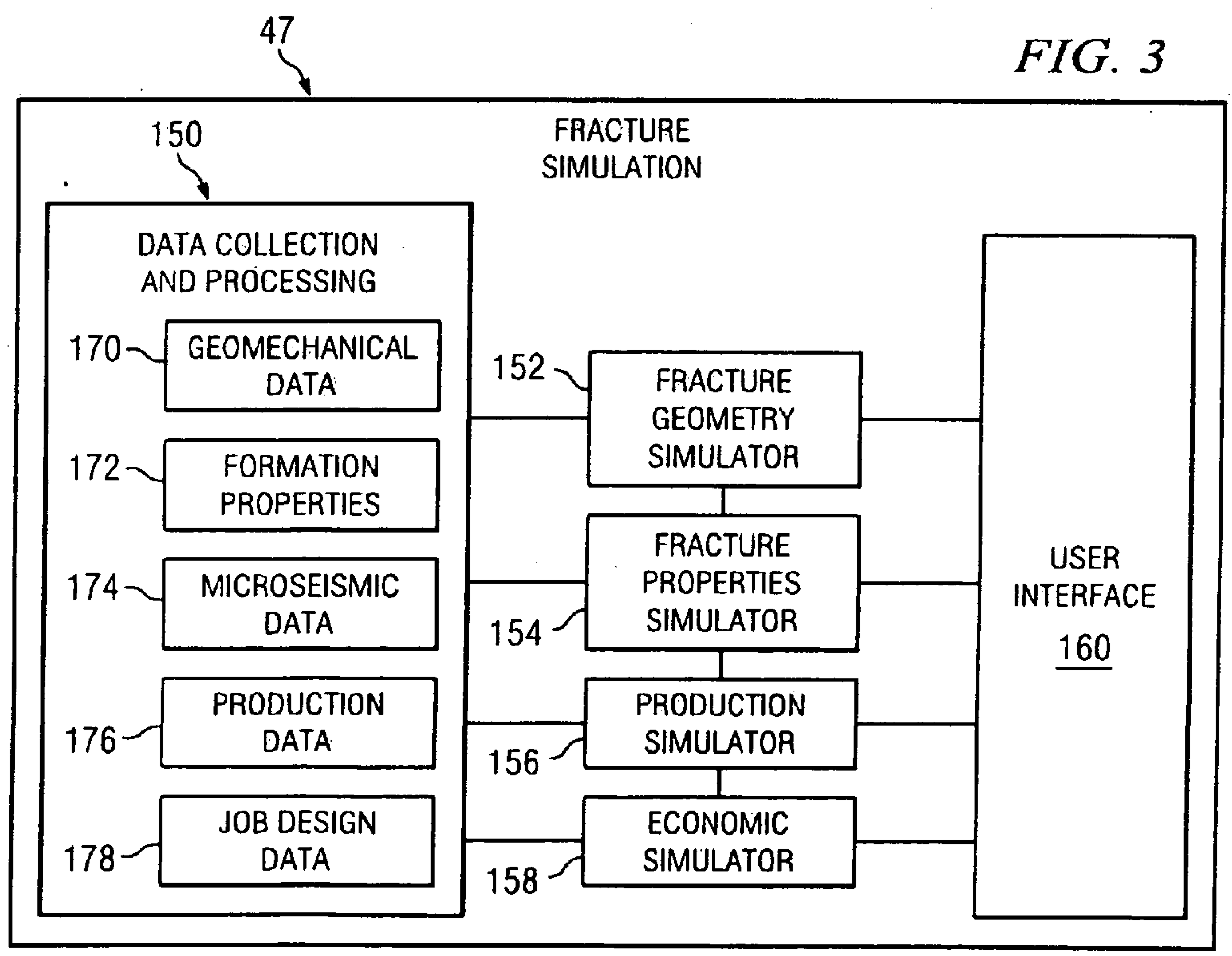
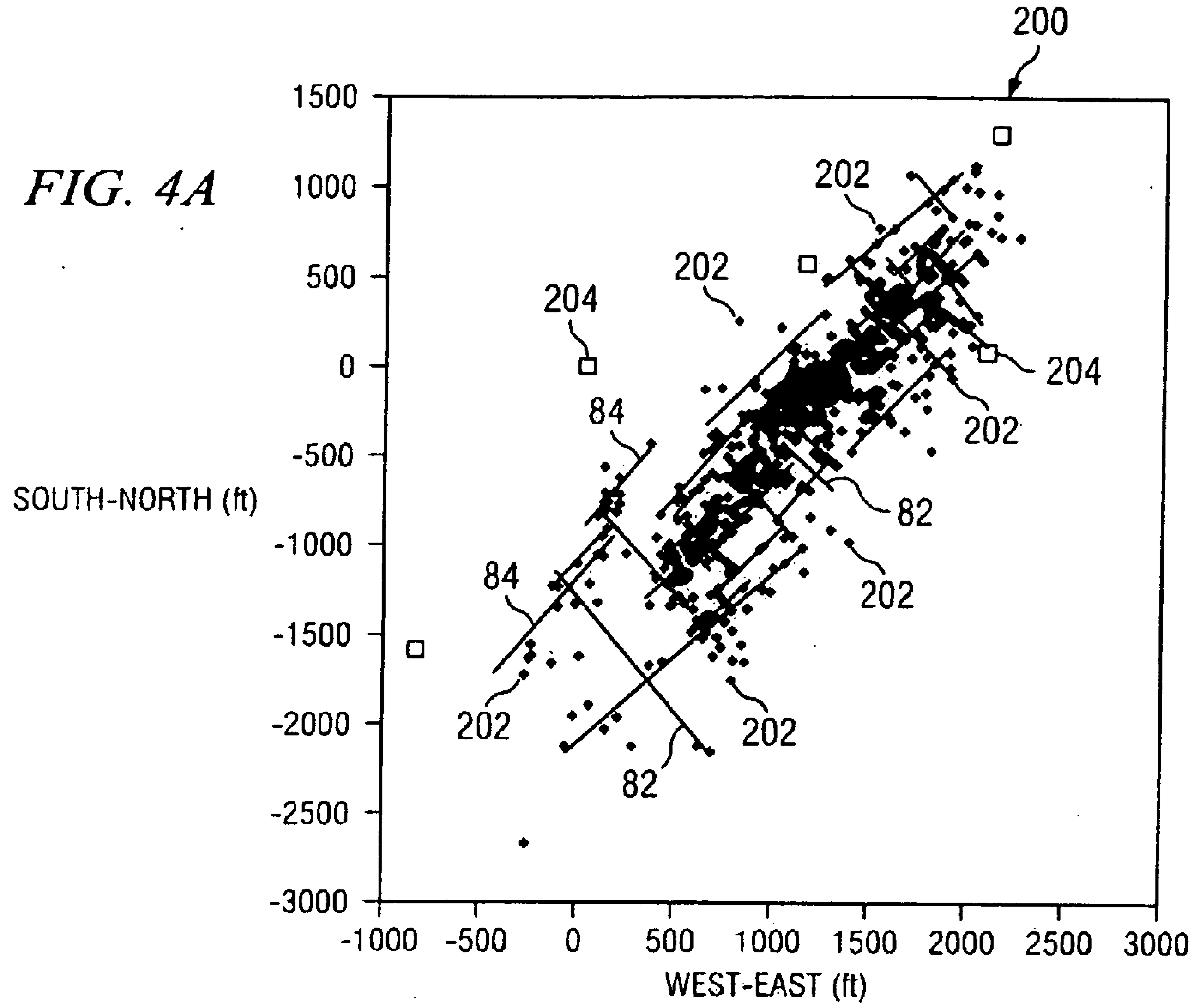

47
FRACTURE SIMULATION
150
DATA COLLECTION AND PROCESSING
170
GEOMECHANICAL DATA
172
FORMATION PROPERTIES
174
MICROSEISMIC DATA
176
PRODUCTION DATA
178
JOB DESIGN DATA
152
FRACTURE GEOMETRY SIMULATOR
154
FRACTURE PROPERTIES SIMULATOR
156
PRODUCTION SIMULATOR
158
ECONOMIC SIMULATOR
USER INTERFACE
160

FIG. 4A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1500
1000
500
0
-500
-1000
-1500
-2000
-2500
-3000
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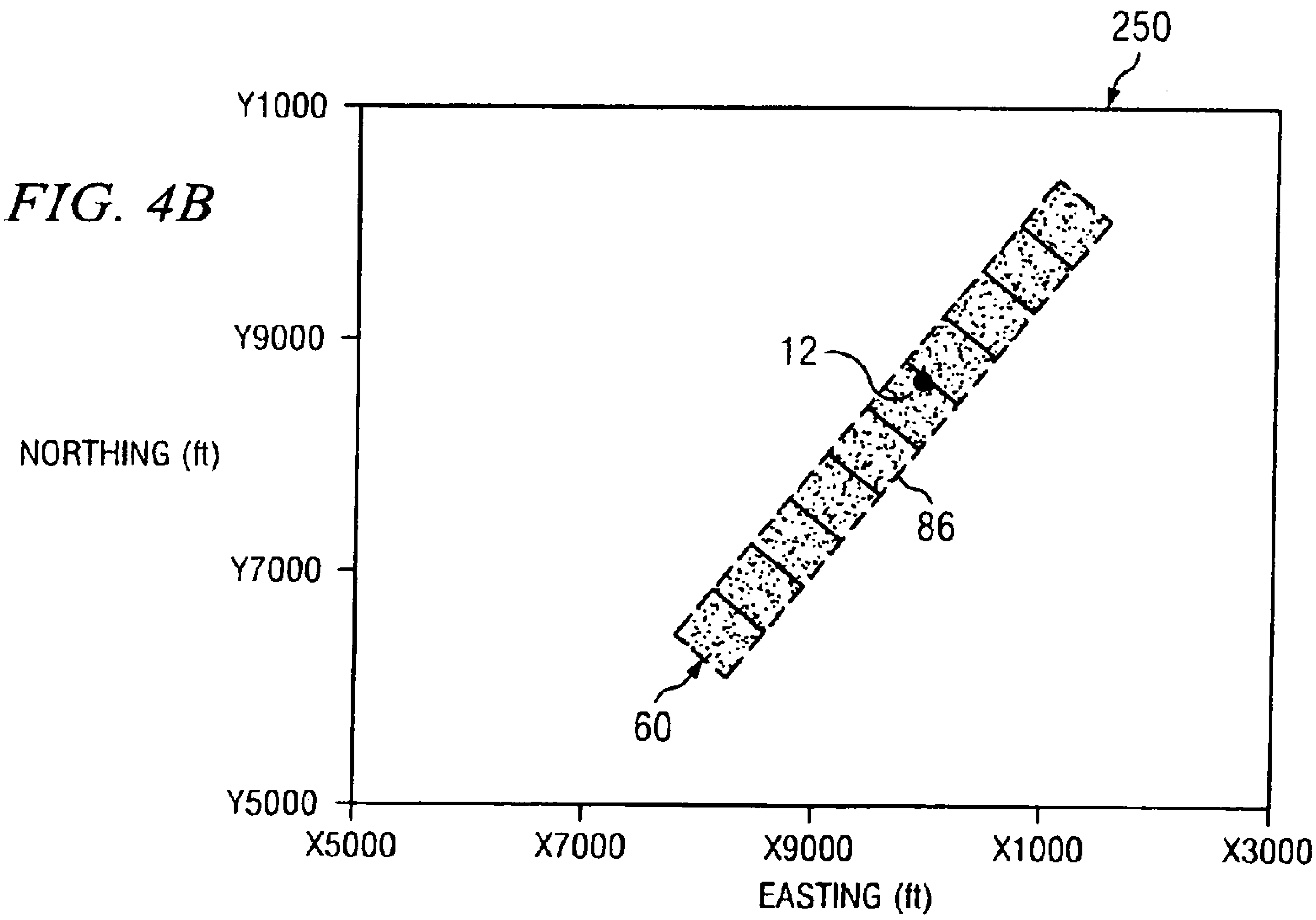
-1000
-500
0
500
1000
1500
2000
2500
3000
WEST-EAST (ft)
202
204
84
82

FIG. 4B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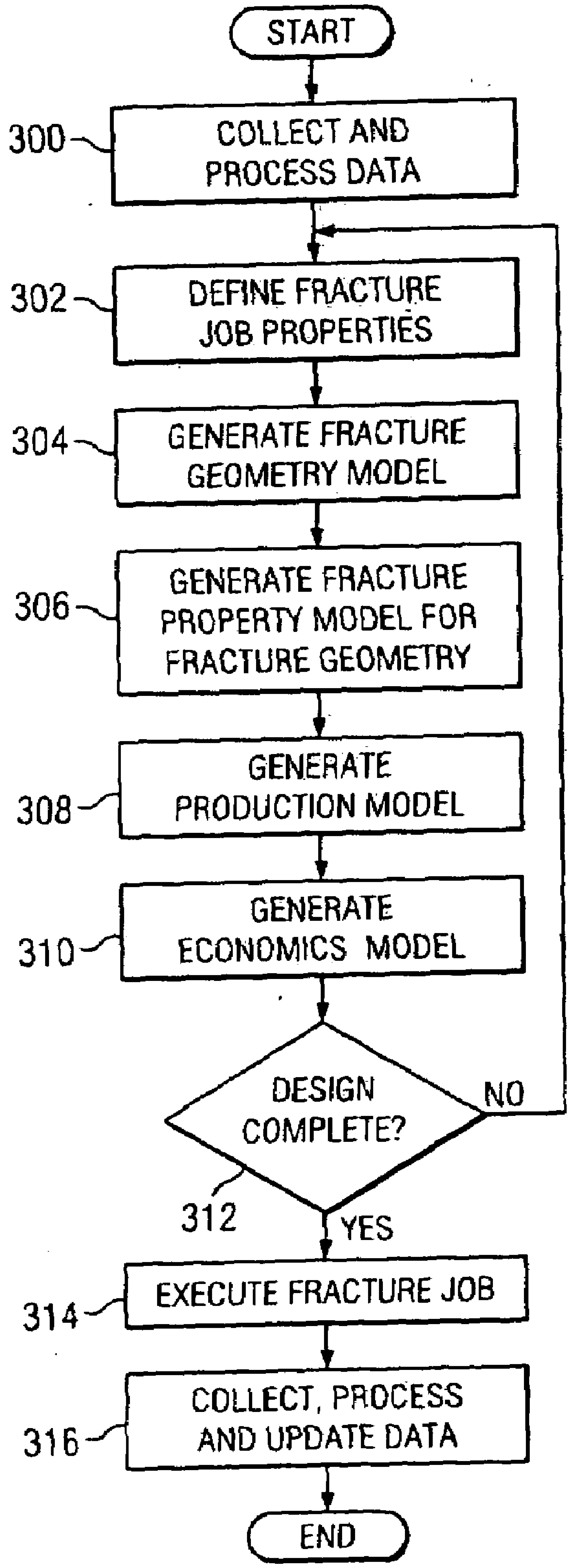
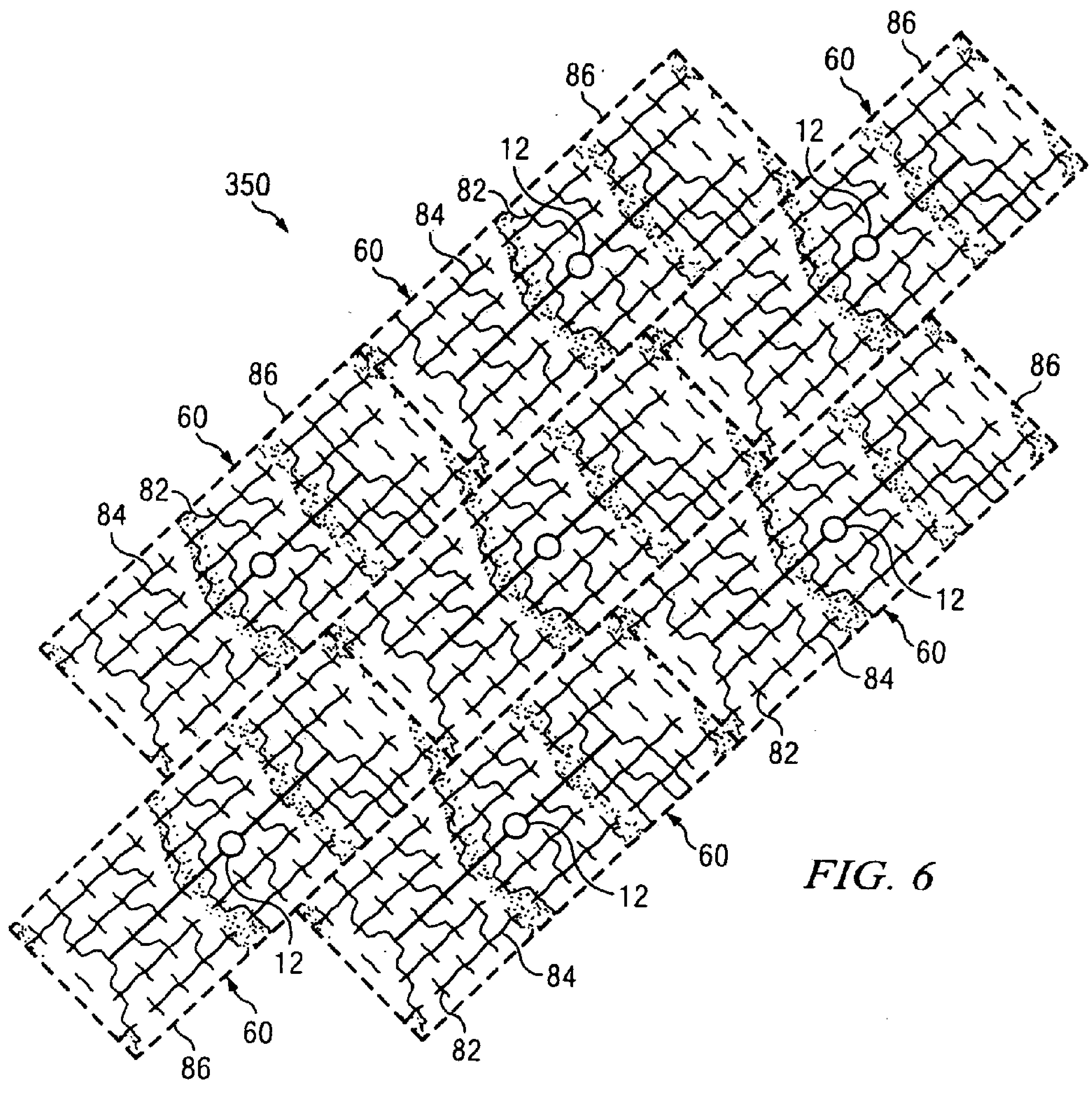
Y1000
Y9000
Y7000
Y5000
NORTHING (ft)
X5000
X7000
X9000
X1000
X3000
EASTING (ft)
12
86
60

FIG. 5


START
300
COLLECT AND PROCESS DATA
302
DEFINE FRACTURE JOB PROPERTIES
304
GENERATE FRACTURE GEOMETRY MODEL
306
GENERATE FRACTURE PROPERTY MODEL FOR FRACTURE GEOMETRY
308
GENERATE PRODUCTION MODEL
310
GENERATE ECONOMICS MODEL
DESIGN COMPLETE?
NO
312
YES
314
EXECUTE FRACTURE JOB
316
COLLECT, PROCESS AND UPDATE DATA
END


350
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12
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82
12
60
84
82
12
60
86
84
82

FIG. 6

METHOD AND SYSTEM FOR DEVELOPMENT OF NATURALLY FRACTURED FORMATIONS

TECHNICAL FIELD

[0001] Fracture stimulation of a well, and more particularly to a method and system for development of naturally fractured formations.

BACKGROUND

[0002] Oil and gas wells produce oil, gas and/or byproducts from underground reservoirs. Oil and gas reservoirs are formations of rock containing oil and/or gas. The type and properties of the rock may vary by reservoir and also within reservoirs. For example, the porosity and permeability of a reservoir rock may vary from reservoir to reservoir and from well to well in a reservoir. The porosity is the percentage of pore volume, or void space, within the reservoir rock that can contain fluids. The permeability is an estimate of the reservoir rock's ability to flow or transmit fluids.

[0003] Oil and gas production from a well may be stimulated by fracture, acid or other production enhancement treatment. In a fracture treatment, fluids are pumped downhole under high pressure to artificially fracture the reservoir rock in order to increase permeability and production. First, a pad, which is fracture fluids without proppants is pumped down the well until formation breakdown. Then, the fracturing fluid with proppants is pumped downhole to hold the fractures open after pumping stops. At the end of the fracture treatment, a clear fluid flush may be pumped down the well to clean the wellbore of proppants.

[0004] Shales and other carboniferous and naturally fractured formations are often fracture stimulated, or treated, to improve natural production. A typical fracture treatment requires thousands to millions of gallons of water with proppant pumped at a high rate of velocity. These fracture treatments are often generic, using little technology to design them. Microseismic monitoring of these fracture treatments indicates the typical fracture pattern is not a single-wing pattern as in other formations, but a maze of induced fractures which engage or hook-up with natural fractures in the shales. The natural fractures are typically, but not always, oriented 90 degrees orthogonal to the direction of the induced fractures or in the direction of minimum horizontal stress. The natural fractures contain natural gas which may be produced after stimulation. For a given volume, several areas of natural fractures are connected by the induced fractures. The improvement from the fracture treatment is a function of the amount of area of the shale that is exposed and allowed to dissorb gas from the formation.

SUMMARY

[0005] A method and system for development of naturally fractured formations are provided. In accordance with one embodiment, a method for development of a naturally fractured formation includes generating a fracture model from a fracture treatment of a well in the naturally fractured formation. The fracture model accounts for natural fractures in the naturally fractured formation. The fracture model may include a fracture volume generated by the fracture treatment. At least one of well spacing and fracture treatment design for one or more wells in the naturally fractured formation may be determined based on the fracture model.

[0006] In a specific embodiment, microseismic data may be used to define the boundaries of the fracture volume. The performance of the fracture may be defined in the classical planar bi-wing fracture, fracture volume, or a fracture volume surrounding a bi-wing fracture. The characterization of fracture volume may be in terms of a new storativity, transmissibility, and/or the fracture's permeability. These parameters may be determined from, for example, either testing or history matching of production. The model may be used for long-term prediction of production.

[0007] Technical advantages of one or more embodiments of the method and system may include providing a fracture simulator which models the fracture geometry of shales and other formations with natural fractures. The model may account for induced and natural fractures. In addition, the model may be calibrated by microseismic data. The model may be used in design and real time modes and provide special three-dimensional models. The design model may be used to plan large field developments.

[0008] Other technical advantages of one or more embodiments may include an integrated approach to stimulation, analysis, reservoir response forecasting and field development planning for shale and other fractured formations. The integrated approach may include the linkage of microseismic measurement, the numerical simulation of the fracture propagation, and the numerical simulation of reservoir performance and/or matching reservoir productivity.

[0009] Details of the one or more embodiments of the disclosure are set forth in the accompanying drawings in the description below. Other features, objects, and advantages of some of the embodiments will be apparent from the description and drawings, and from the claims. Some, all, or none of the embodiments may include advantages described herein.

DESCRIPTION OF DRAWINGS

[0010] FIG. **1** illustrates one embodiment of a fracture treatment for a well;

[0011] FIG. **2** illustrates an exemplary fracture value generated by the fracture treatment of FIG. **1**;

[0012] FIG. **3** illustrates one embodiment of the fracture simulator;

[0013] FIGS. **4**A-B illustrate exemplary inputs and outputs of the fracture simulator of FIG. **3**;

[0014] FIG. **5** illustrates one embodiment of a method for development of a naturally fractured formation using fracture simulation, analysis and reservoir response forecasting; and

[0015] FIG. **6** illustrates exemplary development of a field using fracture treatments.

DETAILED DESCRIPTION

[0016] FIG. **1** illustrates one embodiment of a fracture treatment **10** for a well **12**. The well **12** may be an oil and gas well intersecting a reservoir or formation **14**. In this embodiment, the formation **14** comprises an underground formation of naturally fractured rock containing oil and/or gas. For example, the formation **14** may comprise a fractured shale. The well **12** may in other embodiments, intersect other suitable types of formations **14**, including reservoirs that are not naturally fractured in any significant amount.

[0017] The fracture treatment **10** may comprise a mini fracture test treatment or other suitable treatment. In the mini fracture test treatment embodiment, the fracture treatment **10** may be used to determine formation properties and fracture properties before a regular or full fracture treatment. The formation properties may comprise, for example, reservoir pressure and formation permeability. The formation permeability is an estimate of the reservoir rock's ability to flow or transmit fluids. The fracture properties may comprise, for example, a fracture value and distribution of fractures in the fracture value. In other embodiments, the fracture treatment **10** may comprise a regular or full fracture treatment, a follow-on fracture treatment, a final fracture treatment or other suitable fracture treatment.

[0018] For a mini fracture embodiment, analysis of the test typically is used to determine, for example, the formation permeability, fracture closure pressure, and fissure opening pressure. The fracture closure pressure may be very close to the maximum horizontal stress and may be shown by deviation of the induced fracture from a straight line emanating from the well **12**. In addition, the effective permeability of the fractured system may be determined from analysis of the induced fracture. The mini fracture test may also be used to estimate the dual porosity parameters.

[0019] The presence of pre-hydraulic production data or a test could also or instead be used to determine original storativity and transmissibility. This would provide dual porosity parameters for the original reservoir and for the fracture volume. In another embodiment, production data may be matched with theoretically simulated data from a simulator such as QUIKLOOK from HALLIBURTON. In real time operation, the prediction of the reservoir performance can be used to enhance or optimize the design of the fractured volume. Real time monitoring of seismic can determine whether the design has been achieved and/or the fracture that was achieved. The improved reservoir description may be used to give better forecast of future performance.

[0020] The well **12** may include a well bore **20**, casing **22** and well head **24**. The well bore **20** may be a vertical or deviated bore. The casing **22** may be cemented or otherwise suitably secured in the well bore **12**. Perforations **26** may be formed in the casing **22** at the level of the formation **14** to allow oil, gas, and by-products to flow into the well **12** and be produced to the surface **25**. Perforations **26** may be formed using shape charges, a perforating gun or otherwise.

[0021] For the fracture treatment **10**, a work string **30** may be disposed in the well bore **20**. The work string **30** may be coiled tubing, sectioned pipe or other suitable tubing. A fracturing tool **32** may be coupled to an end of the work string **30**. The fracturing tool **32** may comprise a SURGIFRAC or COBRA FRAC tool manufactured by HALLIBURTON or other suitable fracturing tool. Packers **36** may seal an annulus **38** of the well bore **20** above and below the formation **14**. Packers **36** may be mechanical, fluid inflatable or other suitable packers.

[0022] One or more pump trucks **40** may be coupled to the work string **30** at the surface **25**. The pump trucks **40** pump fracture fluid **58** down the work string **30** to perform the fracture treatment **10** and generate the fracture **60**. The fracture fluid **58** may comprise a fluid pad, proppants and/or a flush fluid. The pump trucks **40** may comprise mobile vehicles, equipment such as skids or other suitable structures.

[0023] One or more instrument trucks **44** may also be provided at the surface **25**. The instrument truck **44** may include a fracture control system **46** and a fracture simulator **47**. The fracture control system **46** monitors and controls the fracture treatment **10**. The fracture control system **46** may, in one embodiment, control the pump trucks **40** and fluid valves to stop and start the fracture treatment **10** as well as to stop and start the pad phase, proppant phase and/or flush phase of the fracture treatment **10**. The fracture control system **46** communicates with surface and/or subsurface instruments to monitor and control the fracture treatment **10**. In one embodiment, the surface and subsurface instruments may comprise surface sensors **48**, down-hole sensors **50** and pump controls **52**.

[0024] Surface and down-hole sensors **48** and **50** may comprise pressure, rate, temperature and/or other suitable sensors. Pump controls **52** may comprise controls for starting, stopping and/or otherwise controlling pumping as well as controls for selecting and/or otherwise controlling fluids pumped during the fracture treatment **10**. Surface and down-hole sensors **48** and **50** as well as pump controls **52** may communicate with the fracture control system **46** over wire-line, wireless or other suitable links. For example, surface sensors **48** and pump controls **52** may communicate with the fracture control system **46** via a wire-line link while down-hole sensors **50** communicate wirelessly to a receiver at the surface **25** that is connected by a wire-line link to the fracture control system **46**. In another embodiment, the down-hole sensors **50** may upon retrieval from the well **12** be directly or otherwise connected to fracture control system **46**.

[0025] The fracture simulator **47** may simulate the fracture **60** during a design phase and/or use data collected from the fracture treatment **10** to simulate further fracture treatments **10** in the formation **14**. In either case, the fracture simulator **47** may be updated during and after the fracture treatment **10** based on measured and/or observed data, including fracture, subsequent production and/or other data. The fracture simulator **47** may also be used for planning field development. For example, the fracture simulator **47** may estimate or otherwise determine fracture geometry based on fracture volume pumped (v_p), determine production based on fracture geometry and/or determine economically optimal or other well spacing and fracture treatment design for field development.

[0026] In one embodiment, the fracture simulator **47** may consider the considerable increase in fluid leak-off and the creation of fractures that are at angle to the main induced hydraulic fractures. The presence of these natural fractures may cause the arrest of the propagation of the main fracture. In particular, the simulator **47** may set limits of the fracture propagation model (both in direction of the main fracture and in a direction perpendicular to the main fracture) from the micro seismic monitoring, set up the three determined stresses, and design the main fracture while varying the leak-off into the formation to get the length determined by micro seismic. The simulator **47** may also use the observed maximum horizontal stress (from mini fracture) and the observed pressure coupled with the length determined from micro seismic to calculate the volume necessary to create the fracture. By comparing the volume leaked off from the first fracture to the volume needed to create the second fracture, a measure of fracture distribution can be reached.

[0027] The fracture simulator **47** may communicate with a microseismic system **56**. The microseismic system **56** may comprise one or more sensors at the surface and/or in an observation well normal to the fracture plane. The microseismic system **56** may detect, record and provide information on points in the formation **14** at which fracturing is observed. In another embodiment, tilt meters or other sensors able to collect information indicative of the area of the formation **14** effected by the fracture **60** may be used in addition to and/or in place of the microseismic system **56**.

[0028] In operation, the fracturing tool **32** is coupled to the work string **30** and positioned in the well **12**. The packers **36** are set to isolate the formation **14**. The pump trucks **40** pump fracture fluid **58** down the work string **30** to the fracturing tool **32**. The fracture fluid **58** exits the fracturing tool **32** and creates the fracture **60** in the formation **14**. In a particular embodiment, a fracture fluid **58** may comprise a fluid pad pumped down the well **12** until breakdown of the formation in the formation **14**. Proppants may then be pumped downhole followed by a clear fluid flush. The fracture treatment **10** may be otherwise suitably performed.

[0029] During the fracture treatment **10**, the microseismic system **56** collects data on the location in the formation **14** where rock slips and/or other fracturing occurs. Additionally, or alternately, the microseismic system **56** may record rock slips and/or other activity indicative of the location of fractures during closure of the fracture **60** following the fracture treatment **10**. The fracture simulator **47** may develop, refine, or otherwise generate a fracture model of the fracture **60** based on microseismic data collected by the microseismic system **56**. As described in more detail below, the fracture model may include a fracture volume of the fracture **60** and/or a fracture geometry of the fracture **60**. The fracture geometry may include the fracture volume as well as storativity and transmissibility of the fracture volume.

[0030] FIG. **2** illustrates one embodiment of the fracture **60** formed from the well **12** in the formation **14**. The fracture **60** includes a swarm or pattern of fractures **80**. The fractures **80** include natural fractures **82** and induced fractures **84**. The induced fractures **84** are perpendicular to the natural fractures **82** and formed by fracture treatment **10**. The natural fractures **82** may be elongated, enlarged or otherwise affected by the fracture treatment **10**. Together, the natural fractures **82** and induced fractures **84** form the effected zone, or other fracture volume **86**.

[0031] In the fracture volume **86**, one or more individual fractures **84** may emit from the well bore and each intersect several natural fractures **82**. Most, if not all, natural fractures **82** will take fluid but some will divert the flow from the induced fracture **84** so that the flow quits its original path and instead fluid goes down the natural fracture **82**. At some point, the natural fracture **82** may cease to exist, in which case the energy in this portion of a fracture **60** is sufficient to re-start an induced fracture **84** along the original fracturing plane. The induced hydraulic fracture **84** will typically be located in the middle of the fracture volume **86**. The boundaries of the fracture volume **86** may be determined from seismic data. In some embodiments, the fracturing treatment will not change the basic parameters of fracture volume **86**, but will change the dimensions of the fracture volume **86** (will get bigger).

[0032] The induced fractures **84** may provide primary porosity in the fracture volume **86** while the natural fractures **82** provide secondary porosity. The fracture swarm may have ratios of about forty percent (40%) induced fractures **84** (and fracture length) in the fracture volume **86** about forty-five percent (45%) natural fractures **82** (and fracture length) in the fracture volume **86** and about five percent (5%) horizontal fractures (associated with either natural or induced) in the fracture volume **86**.

[0033] FIG. **3** illustrates one embodiment of the fracture simulator **47**. In this embodiment, the fracture simulator **47** is implemented as an integrated computer system such as a personal computer, laptop, or other stand-alone system. In other embodiments, the fracture simulator **47** may be implemented as a distributed computer system with elements of the fracture simulator **47** connected locally and/or remotely by a computer or other communication network.

[0034] The fracture simulator **47** may comprise any processors or set of processors that execute instructions and manipulate data to perform the operations such as, for example, a central processing unit (CPU), a blade, an application specific integrated circuit (ASIC), or a field-programmable gate array (FPGA). Processing may be controlled by logic which may comprise software and/or hardware instructions. The software may comprise a computer readable program coded and embedded on a computer readable medium for performing the methods, processes and operations of the respective engines.

[0035] Referring to FIG. **3**, the fracture simulator **47** includes a data collection and processing unit **150**, fracture geometry simulator **152**, a fracture property simulator **154**, a production simulator **156**, an economic simulator **158**, and user interface **160**. The fracture simulator **47** and/or components of the fracture simulator **47** may comprise additional, different, and/or other suitable elements, as well as any suitable subset of the elements.

[0036] Data collection and processing unit **150** receives, accesses, and/or stores geomechanical data **170**, reservoir properties **172**, microseismic data **174**, production data **176** and job design data **178** for the formation **14**, which may include data for similar formations if appropriate. Additional, different and/or other suitable information may be collected, stored and/or accessed, as well as any suitable subset of information. The collection and processing unit **150** may correlate received signals to a corresponding measured value, filter the data, fill in missing data and/or calculate data derivatives used by one or more of the fracture geometry simulator **152**, fracture property simulator **154**, production simulator **156** and/or economic simulator **158**. The data collection and processing unit **150** may comprise data input/output (I/O) and data storage. The data I/O may be coupled by wireline or wirelessly to local and/or remote instruments or data sources. The data storage may be one or more databases or other persistent or non-persistent storage.

[0037] The geomechanical data **170** may be received from database sources, from imaging logs such as Formation Micro-Imager (FMI) or otherwise. In the FMI embodiment, the FMI tool determines a maximum horizontal stress (υ_H max), a minimum horizontal stress (υ_H min), stress directions, and the relationship between the maximum and minimum stresses. The FMI tool may comprise, for example, a 4, 5 or 6 arm tool. This and other or different geomechanical information is stored in geomechanical data **170**.

[0038] The reservoir properties data **172** may be received from database sources, from well logs or otherwise. The reservoir properties **172** may comprise, for example, rock mechanic properties such as Young's Modulus, Poisson's Ratio, fracture stress, permeability, thickness, pressure, porosity, and spacing of natural fractures **82**. The reservoir properties **172** may comprise other suitable data indicative of formation **14** and/or conditions in the formation **14**.

[0039] The microseismic data **174** may be collected from the microseismic system **56**, or other suitable sources. The microseismic data **174** may comprise the distribution of natural and induced fractures **82** and **84** for fracture treatments **10** in the formation **14**, as well as the fracture value generated by the fracture treatments **10**. Measured microseismic data may be processed by manually or otherwise plotting points where rock slips during the fracture treatment **10**, which may be recorded as pops or snaps during the fracture treatment **10**. The points may be in or just outside the natural fractures **82** and/or induced fractured **84**. The microseismic data **174** may comprise other, different and/or additional information, as well as a subset of the described information.

[0040] The production data **176** may be directly measured and/or received from database sources or otherwise. The production data **176** may comprise oil, gas and/or water production data as well as bottom hole pressure and temperature information from wells drilled and producing in the formation **14**. The production data **176** may also comprise production and other decline data, as well as other information indicative of production. Production data **176** may comprise other, additional or different information, as well as a subset of the described information.

[0041] The job design data **178** may comprise data for a planned fracture treatment **10**. The job design data **178** may include a fracture volume **86**, volume pumped for the fracture treatment **10** and/or rate (Q) for the fracture treatment **10**. In one embodiment, simulations of the fracture simulator **47** are based on volume pumped data for a planned fracture treatment **10**. In this embodiment, fracture geometry may be simulated based on volume pumped. The simulation may be based on additional or different data. The job design data **178** may comprise other, different and/or additional data for the planned fracture treatment **10**, as well as a subset of the identified data.

[0042] The fracture geometry simulator **152**, fracture property simulator **154**, production simulator **156** and economic simulator **158** may each be coupled to the data collection and processing unit **150** and the user interface **160**, as well as to each other. Accordingly, each may access data collected, calculated and/or simulated and each may be accessed by an operator or other user via the user interface **160**. The user interface **160** may comprise a graphical interface, a text based interface or other suitable interface. In a particular embodiment, the fracture geometry simulator **152** may provide a fracture geometry model and/or access to the fracture geometry model to the fracture property simulator **154**. Similarly, the fracture property simulator **154** may provide a fracture property model and/or access to the fracture property model to the production simulator **156**. The production simulator **156** may provide a production model or access to a production model to the economic simulator **158**. Accordingly, each simulator may store its own generated model and/or may transfer the model to another simulator for processing. In another embodiment, models may be stored in the data collection and processing unit **150** and/or displayed by the user interface **160**. The simulations may in a particular embodiment be generated and/or displayed in real-time to the input of job design data and/or at a fracture site.

[0043] The fracture geometry simulator **152** may simulate, or model, geometry of the fracture **60** generated by a planned fracture treatment **10** based on volume pumped or the job design data **178** for the planned fracture treatment **10**. An operation is based on data or another element when it uses and/or accounts for the data or other element. Accordingly, the operation may also use and/or account for other data and other information. A generated fracture geometry model may comprise fracture volume **86**. In a particular embodiment, the fracture geometry model may also comprise the distribution and/or pattern of the natural fractures **82** and induced fractures **84**.

[0044] The fracture geometry simulator **152** provides in one embodiment a dual porosity model that accounts for natural fractures **82** as well as geomechanical data **170** and reservoir properties **172**. In this embodiment, the fracture geometry model may be based on volume pumped for the fracture **60** and distance from the well bore **20** of the natural fractures **82** and induced fractures **84**. The fracture geometry may be otherwise simulated, estimated or otherwise determined, by the fracture geometry simulator **152**.

[0045] The fracture properties simulator **154** may simulate, or model, fracture properties based on the fracture geometry model generated by the fracture geometry simulator **152** and the volume pumped or other job design data **178**. The fracture properties may be otherwise simulated, estimated or otherwise determined by the fracture property simulator **154**. In simulating fracture properties, the fracture property simulator **154** may, for example, account for natural fractures **82** and induced fractures **84**, as well as geomechanical data **170**, and reservoir properties **172**. In a particular embodiment, fracture properties may comprise storativity (ω) and transmissibility (4). Storativity is the ratio of the fracture volume to the total system volume. Transmissibility is proportional to the ratio of matrix permeability to the natural fracture system. The created fracture volume **86** will typically have larger storativity, smaller transmissibility and higher fractured system permeability. The fracture permeability may increase by the same ratio of the decrease in transmissibility. The change in storativity, transmissibility, and fracture permeability may be a result of ballooning the naturally fractured system around the created hydraulic fracture.

[0046] The fracture geometry simulator **152** and fracture property simulator **154** may be calibrated using geomechanical data **170**, reservoir properties **172**, microseismic data **174**, and/or production data **176**. In a particular embodiment, the fracture geometry simulator **152** may be calibrated by correlating volume pumped for fracture treatments **10** in formation **14** with fracture volume **86** generated by the fracture treatments **10** as determined by microseismic data **174** for the fracture treatments **10**. For example, the fracture property simulator **154** and fracture geometry simulator **152** may create a distribution of fracture geometry in terms of percentage into the induced fracture azimuth, natural fracture azimuth and horizontal components. These simulators can be calibrated by taking measurements from geomechanical properties, micro seismic studies of area fracture treatments, known reservoir properties such as lambda and omega, plus other reservoir components mentioned above. The output would be similar to FIG. **2** which indicates a plane view of the fracture network system. In one embodiment, an example of output would be: "40% induced, 55% natural and 5% horizontal components." These values may then be used to determine the fracture value of the fracture network. This fracture volume can be input into the reservoir model to determine economical benefit from the volume of fluid pumped.

[0047] In addition, the fracture property simulator **154** may in a particular embodiment be calibrated by correlating volume pumped and fracture volume **86** for fracture treatments **10** in formation **14** with production data **176** resulting from the fracture treatments **10** to simulate, estimate or otherwise determine fracture properties. For example, storativity and transmissibility correlating to a pumped volume and fracture volume **86** may be adjusted to values that account for measured production from fracture treatments **10** in the formation **14**. As another example, leak off parameters and properties of the formation **14** surrounding the fracture **16** may be modified to match observed fracture growth as a fracture **60** and as a total area surrounding the fracture **60**. In particular, a non-linear regression may be used to vary storativity and transmissibility until a calculated production curve matches observed production. The fracture property simulator **154** may be otherwise suitably calibrated.

[0048] The production simulator **156** simulates production for a planned fracture treatment **10** based on the fracture model generated by the fracture geometry simulator **152** and fracture property simulator **154**. The fracture model may comprise the fracture volume **86** determined by the fracture geometry simulator **152** and the storativity and transmissibility of the fracture volume **86** determined by the fracture property simulator **154**. The fracture model may provide geometry and growth patterns with time (volume of fluid pumped) to replicate the longitudinal and horizontal growth of the fracture network. The fracture model may also include, for example, distribution of the induced and natural fractures **82** and **84**. The fracture model may comprise other suitable criteria for determining production from the fracture treatment **10**. In addition, the production simulator **156** may simulate production from a performed fracture treatment **10** based on actual data measured during or after the fracture treatment **10**, such as microseismic data, as well as measured or simulated fracture properties. In another embodiment, the fracture model will be generated without the fracture geometry model. In this embodiment, the microseismic effect may be matched. For example, a natural fracture model can be generated from micro seismic observations and matched to induced fractures **84**.

[0049] The production simulator **156** may simulate oil, gas and/or water or other byproduct production, as well as production incline and decline curves. In one embodiment, the simulated production, or production model, comprises oil and water production curves over the expected life of the well **12**. The production curves may be printed, displayed in the user interface **160** or otherwise made available to the operator. In a particular embodiment, the production curves may plot volume produced in barrels or other units versus time in years. The production similar **156** may be calibrated by correlating measured storativity and transmissibility from fracture treatments **10** in wells **12** in the formation **14** to measured production of the wells **12**.

[0050] The economic simulator **158** simulates economics of the planned fracture treatment **10** for the well **12** based on, in one embodiment, cost of the fracture treatment **10** and revenue generated by the well **12** in response to the fracture treatment **10**. In a particular embodiment, the economic simulator **158** may determine the volume pumped or other criteria for the fracture treatment **10** based on balancing costs of the fracture treatment **10** versus increased revenues from the fracture treatment **10**. The economic simulator **158** may account for increased and/or earlier production when weighing various treatment design options. The design of the planned fracture treatment **10** may be enhanced or optimized by iteratively simulating the economics of various treatment designs. For example, a number of treatment designs may be fed into the fracture simulator **47** and a fracture geometry model, fracture property model, production model and economic model generated for each treatment design, with the treatment design leading to the most economic model selected for the fracture treatment **10**.

[0051] In addition, or alternately, well spacing for wells **12** in the formation **14** may be determined based on fracture economics. In this embodiment, well spacing may be selected to enhance or optimize revenues from production of the field. For example, cost of well formation versus cost of well fracturing, as well as resulting production, may be evaluated for the field. It may, in some cases, be economically advantageous to drill an increased number of wells **12** that each need a smaller fracture volume **86** than to drill a decreased number of wells **12** each needing an increased fracture volume **86** to complete the field, or vice versa. In a particular embodiment, an optimum well spacing and the corresponding fracture volume **86** for the wells **12** may be selected to complete the field. In addition to fracture treatment **10**, well spacing and field planning, the fracture simulator **47** may be used after a fracture treatment **10** to simulate production and economics based in microseismic or other data from the fracture treatment **10**. In this embodiment, the production simulation includes the effect of fracture **60** as well as the total affected formation **14**, or reservoir, volume as observed from microseismic measurements. In still another embodiment, the existing microseismic data may be used to perform matching after-treatment to calibrate the model and further refine the terms that represent the natural fractures **82** which may be the ratio of fluid that occupies or propagates into the natural fracture **82** system versus the induced fracture **84** system. In other words, if the output is 50/45/05, then 45 percent of the fracture volume propagates into the natural fracture **82** system and 50 percent propagates into the induced fracture **84** system. Horizontal fracture geometries typically range from 7 percent down to 2 percent. Therefore, in one embodiment, a common output from the model would be dependent upon volume pumped. As a first example, volume is 1,000,000 gallons of fracture fluid (water) and fracture height to be stimulated is 600 feet. Rate is 85 barrels per minute. Output is 52/45/03, which translates to 52 percent induced fractures **82**, 45 percent natural fractures **84**, and 3 percent horizontal fractures. The model would generate these geometries with time and the horizontal geometries not appearing until late in the treatment. As a second example, volume is 3,500,000 gallons of fracture fluid (water) with the other fracture values the same as the first example. Output is 48/48/04, which translates to 48 percent induced fracture **82**, 48 percent natural fractures **84** and 4 percent horizontal fractures. This example generates a differently shaped rectangle in the plan view than the first example. The overall area is greater as more fluid is injected, but the final shape would resemble a square more so than in the first example.

[0052] In still another embodiment, existing microseismic data and production data may be used and a multiple history matching approach, to evaluate the success or lack of it from the fracturing treatment **10**. In this embodiment, the model would include geomechanics effect and may also indicate whether the affected volume by the fracture treatment **10** has been closing or has already closed.

[0053] FIGS. **4**A-B illustrate exemplary inputs and outputs of the fracture simulator **47**. In particular, FIG. **4**A illustrates a microseismic map **200** from a fracture treatment **10**. FIG. **4**B illustrates an exemplary fracture model **250** display generated by the fracture simulator **47** for a planned fracture treatment **10**. The fracture simulator **47** may comprise other or different suitable inputs and outputs.

[0054] Referring to FIG. **4**A, the microseismic map **200** comprises measured data. In one embodiment, the microseismic map **200** comprises a number of points **202** where the rock slipped in formation **14** during the fracture treatment **10**. As previously described, the slips may be recorded as pops or snaps during the fracture treatment **10**. The points **202** may be just inside the natural fractures **82** and/or induced fractures **84**. The microseismic map **200** may include plotted natural fractures **82** and induced fractures **84**. The microseismic map **200** may be two-dimensional and indicate location within the field. In another embodiment, the microseismic map **200** may be three-dimensional indicating rock slips **202**, natural fractures **82** and induced fractures **84** at different depths of the formation **14**. An observation well **204** from which the data was recorded may also be recorded on the microseismic map **200**.

[0055] Referring to FIG. **4**B, the fracture model display **250** may indicate the fracture volume **86** for a planned fracture treatment **10** having a certain job design. Storativity and transmissibility of the fracture **60** in the fracture volume **86** may be indicated (not shown) as well as the job design data (not shown). In addition, distribution of natural and induced fractures **82** and **84** may also be indicated as well as the location of the well **12**. The fracture model display **250** may comprise a two-dimensional or three-dimensional display. In the three-dimensional embodiment, the fracture model display **250** may display variations in fracture distribution and/or transmissibility or storativity by depth of the formation **14**. The fracture model **250** may be otherwise suitably displayed to the operator in textural, other graphical and/or other forms.

[0056] FIG. **5** illustrates one embodiment of a method for development of a naturally fractured formation using fracture simulation, analysis and reservoir response forecasting. In this embodiment, the fracture simulator **47** determines an enhanced or optimized fracture design for one or more wells **12** in the formation **14**. Other suitable data and/or simulators may be used without departing from the scope of the invention.

[0057] Referring to FIG. **5**, the method begins at step **300** in which data is collected and processed. In one embodiment, the data includes the geomechanical data **170**, formation properties **172**, microseismic data **174**, and production data **176**. The data may be determined from previous wells **12** in the formation **14** and/or other suitable sources.

[0058] Proceeding to step **302**, fracture job properties are defined. Fracture job properties may be defined in the job design data **178** of fracture simulator **47**. The fracture job properties may comprise a specific design, a set of specific designs and/or one or more specific designs with predefined variations for iterative testing and/or optimization of treatment design. Fracture job properties may be otherwise suitably defined.

[0059] At step **304**, a fracture geometry model may be generated. The fracture geometry model may be generated by the fracture geometry simulator **152** and comprise a fracture volume **86** for a fracture treatment **10**. The fracture geometry model may also comprise the distribution of natural fractures **82** and induced fractures **84**.

[0060] Next, at step **306**, a fracture property model may be generated for the fracture geometry model. The fracture property model may be generated by the fracture property simulator **154**. The fracture property model may comprise the storativity and transmissibility of the formation **14** in the fracture volume **86**. As previously described, the fracture geometry model and fracture property model may together comprise a fracture model. The fracture model may be displayed to the operator as fracture model display **250** or otherwise. In another embodiment, fracture model may not be displayed or available to the operator. Similarly, the fracture geometry model and fracture property model may or may not be displayed to the operator.

[0061] At step **308**, a production model is generated. The production model may be generated by the production simulator **156**. The production model may provide estimated oil, gas and/or water production curves for the well **12** in response to the planned fracture treatment **10**. The production model may be displayed to the operator in graphical or textual form. In another embodiment, the production model may not be displayed to the operator.

[0062] At step **310**, an economic model may be generated for the well **12** based on the production model. The economic model may be generated by the economic simulator **158**. The economic model may provide the net present value or other indication of value to be obtained from the well **12** based on estimated production following the planned fracture treatment **10**. The economic model may also indicate cost of the well **12** including cost of the fracture treatment **10** and/or provide a net gain or loss obtained from the well **12** in response to the fracture treatment **10**.

[0063] Proceeding to decisional step **312**, it is determined if the design of the fracture treatment **10** is complete. Design of the fracture treatment **10** may be complete when the fracture treatment **10** is optimized economically or otherwise or exceeds an economical or other threshold. If design of the fracture treatment **10** is not complete, the No branch of decisional step **312** returns to step **302** where fracture job properties are redefined or otherwise varied. After the fracture treatment **10** has been optimized or the fracture treatment **10** has been selected by an operator, the Yes branch of decisional step **312** leads to step **314**, in which the fracture treatment **10** may be executed based on the optimized or selected design.

[0064] Next, at step **314**, data may be collected during the fracture treatment **10** and used to calibrate or update the fracture simulator **47**. In addition, production and other data may be measured over the life of the well **12** and used to update the fracture simulator **47**. During drilling and production of additional wells **12**, well spacing may be determined based on the optimized or otherwise selected fracture treatment **10** design.

[0065] FIG. **6** illustrates exemplary development of a field **350** using fracture treatments **10**. Referring to FIG. **6**, the field **350** includes a plurality of wells **12** each having a fracture **60**. The fractures **60** include natural fractures **82** and induced fractures **84**. The induced fractures **84** are perpendicular to natural fractures **82** and formed by the fracture treatment **10**. The natural fractures **82** and induced fractures **84** together form the fracture volume **86**.

[0066] The wells **12** may be optimally spaced to allow completion of the field **350** at the least cost and/or greatest revenue. For example, the necessary number of wells **12** and corresponding size of the fracture values **86** for the wells may be determined to produce the field **350** at minimum cost and/or greatest net revenues. Well spacing **12** may deviate in one or more parts of the field based on topology of the field **350** and/or other considerations.

[0067] Although this disclosure has been described in terms of certain embodiments and generally associated methods, alterations and permutations of these embodiments and methods will be apparent to those skilled in the art. Accordingly, the above description of example embodiments does not define or constrain this disclosure. Other changes, substitutions, and alterations are also possible without departing from the spirit and scope of this disclosure.

What is claimed is:

1. A method for development of a naturally fractured formation, comprising:

generating a fracture model from a fracture treatment of a well in a naturally fractured formation;

the fracture model accounting for natural fractures within the naturally fractured formation and comprising a fracture volume of a fracture generated by the fracture treatment; and

determining at least one of well spacing and fracture treatment designed for one or more wells in the naturally fractured formation based on the fracture model.

2. The method of claim **1**, further comprising updating the fracture model based on production data from the well in the naturally fractured formation.

3. The method of claim **1**, further comprising optimizing well spacing and fracture treatment design for the one or more wells in the naturally fractured formation based on the fracture model.

4. The method of claim **1**, wherein the fracture model comprises storativity and transmissibility of the fracture volume.

5. The method of claim **1**, further comprising generating the fracture model based on microseismic data collected from a fracture treatment of a disparate well in the naturally fractured formation.

6. The method of claim **1**, wherein the fracture model comprises a multi-dimensional model.

7. A method for well planning in a formation, comprising:

performing a fracture treatment for a well to generate a fracture in a formation;

collecting microseismic data from the fracture treatment;

using the microseismic data to generate a fracture model of the fracture; and

using the fracture model for well planning in the formation.

8. The method of claim **7**, wherein the well planning comprises at least one of a spacing for a second well based on the fracture model and a fracture treatment design for the second well.

9. The method of claim **7**, further comprising updating the fracture model based on production from the well.

10. The method of claim **7**, further comprising determining a well spacing and a fracture treatment design for one or more wells based on the fracture model.

11. The method claim **10**, further comprising determining the well spacing and fracture treatment design for the one or more wells based on an economic analysis of costs of the fracture treatment design and revenue generated by the one or more wells based on the fracture treatment design.

12. The method of claim **7**, wherein the fracture model comprises storativity and transmissibility of a fracture volume of the fracture generated by the fracture treatment.

13. The method for simulating production enhancement of a well, comprising:

simulating a fracture geometry from a fracture treatment of a well in a formation, the fracture geometry accounting for natural fractures in the formation; and

simulating production of the well based on the fracture geometry.

14. The method of claim **13**, further comprising simulating the fracture geometry based on a volume of the facture treatment.

15. The method of claim **13**, further comprising simulating the fracture geometry based on microseismic data collected for a disparate fracture treatment in the formation.

16. The method of claim **13**, further comprising generating a visual image of the fracture geometry, the visual image comprising induced and natural fractures.

17. The method of claim **14**, wherein the fracture geometry comprises a fracture volume of the fracture treatment.

18. The method of claim **17**, wherein the fracture geometry comprises storativity and transmissibility of the fracture volume.

19. The method of claim **13**, further comprising simulating the fracture geometry by generating a multi-dimensional model of the fracture treatment.

20. The method of claim **19**, further comprising updating the multi-dimensional model based on production for the well.

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