US 20170114616A1

(19) **United States**

(12) **Patent Application Publication**

Enkababian et al.

(10) **Pub. No.: US 2017/0114616 A1**

(43) **Pub. Date: Apr. 27, 2017**

(54) **USE OF DRILLING DATA FOR ENGINEERED COMPLETIONS**

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(21) Appl. No.: **15/242,662**

(22) Filed: **Aug. 22, 2016**

Related U.S. Application Data

(60) Provisional application No. 62/245,395, filed on Oct. 23, 2015, provisional application No. 62/269,396, filed on Dec. 18, 2015.

Publication Classification

(51) **Int. Cl.**

E21B 41/00	(2006.01)
E21B 49/00	(2006.01)
E21B 43/26	(2006.01)
E21B 45/00	(2006.01)

(52) **U.S. Cl.**

CPC ***E21B 41/0092*** (2013.01); ***E21B 45/00*** (2013.01); ***E21B 49/003*** (2013.01); ***E21B 43/26*** (2013.01); *E21B 43/267* (2013.01)

(57) **ABSTRACT**

Methods may include applying a correlation between the probability of stress variations in a first well and variations in drilling data obtained from the first well to drilling data obtained from one or more additional wells; calculating a proportion of high stress and low stress contrast stages within the one or more additional wells; and creating one or more synthetic stress profiles for various completion techniques based on the calculated proportion of high stress and low stress contrast stages within the one or more additional wells; and using the one or more synthetic stress profiles to create a synthetic stress log for a geometric completion (GC) and an engineered completion (EC). Methods may also include obtaining drilling data from one or more wells; calculating a proportion of high stress and low stress contrast stages within the one or more additional wells; and creating one or more synthetic stress profiles for various completion techniques based on the calculated proportion of high stress and low stress contrast stages within the one or more wells.

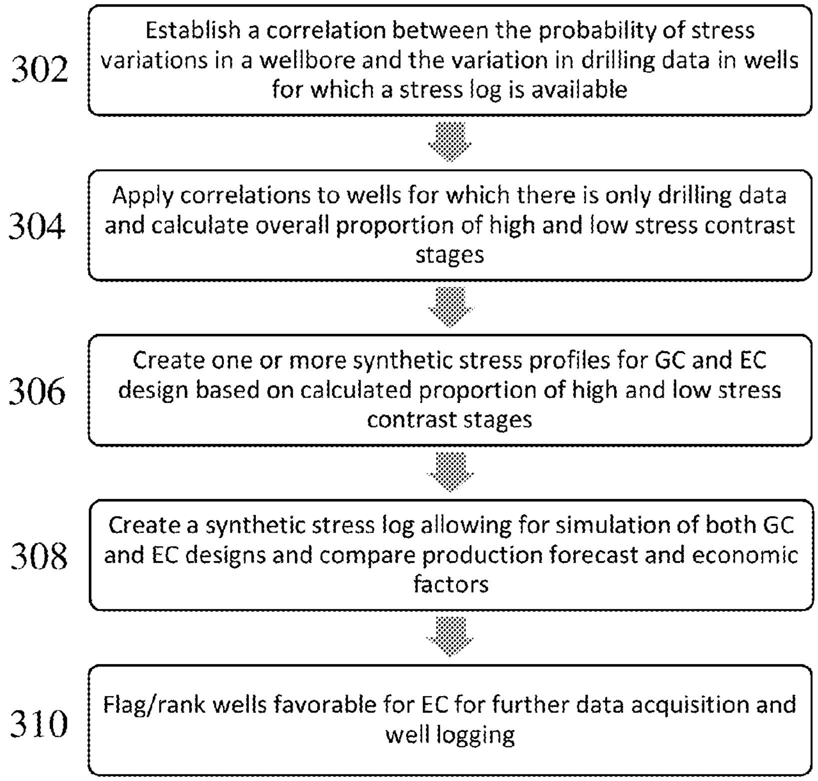


FIG. 1

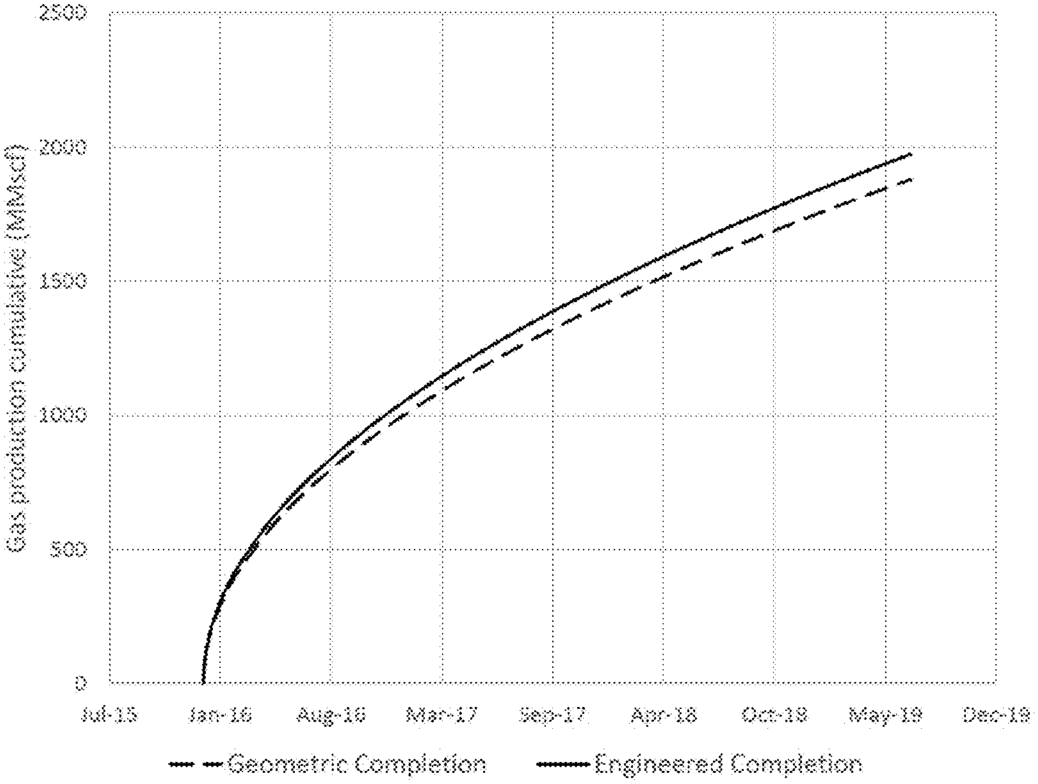

Gas production cumulative (MMscf)
2500
2000
1500
1000
500
0
Jul-15
Jan-16
Aug-16
Mar-17
Sep-17
Apr-18
Oct-18
May-19
Dec-19
Geometric Completion
Engineered Completion

FIG. 2

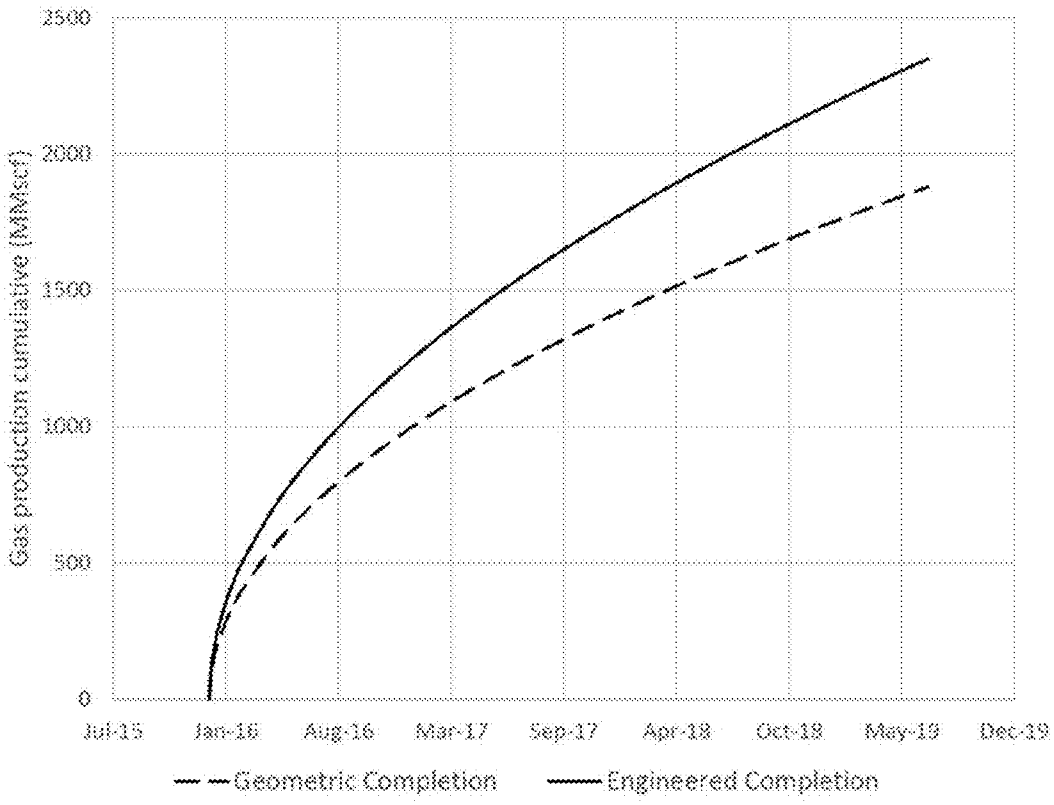

2500
2000
1500
1000
500
0
Gas production cumulative (MMscf)
Jul-15
Jan-16
Aug-16
Mar-17
Sep-17
Apr-18
Oct-18
May-19
Dec-19
Geometric Completion
Engineered Completion

FIG. 3

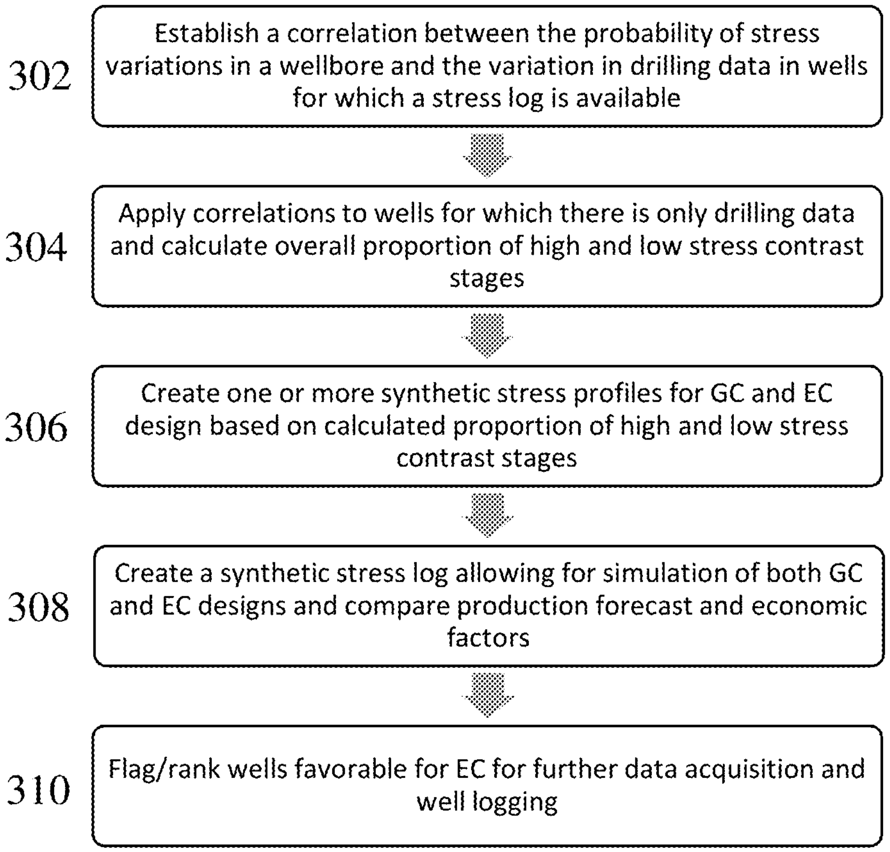

302
Establish a correlation between the probability of stress variations in a wellbore and the variation in drilling data in wells for which a stress log is available
304
Apply correlations to wells for which there is only drilling data and calculate overall proportion of high and low stress contrast stages
306
Create one or more synthetic stress profiles for GC and EC design based on calculated proportion of high and low stress contrast stages
308
Create a synthetic stress log allowing for simulation of both GC and EC designs and compare production forecast and economic factors
310
Flag/rank wells favorable for EC for further data acquisition and well logging

FIG. 4

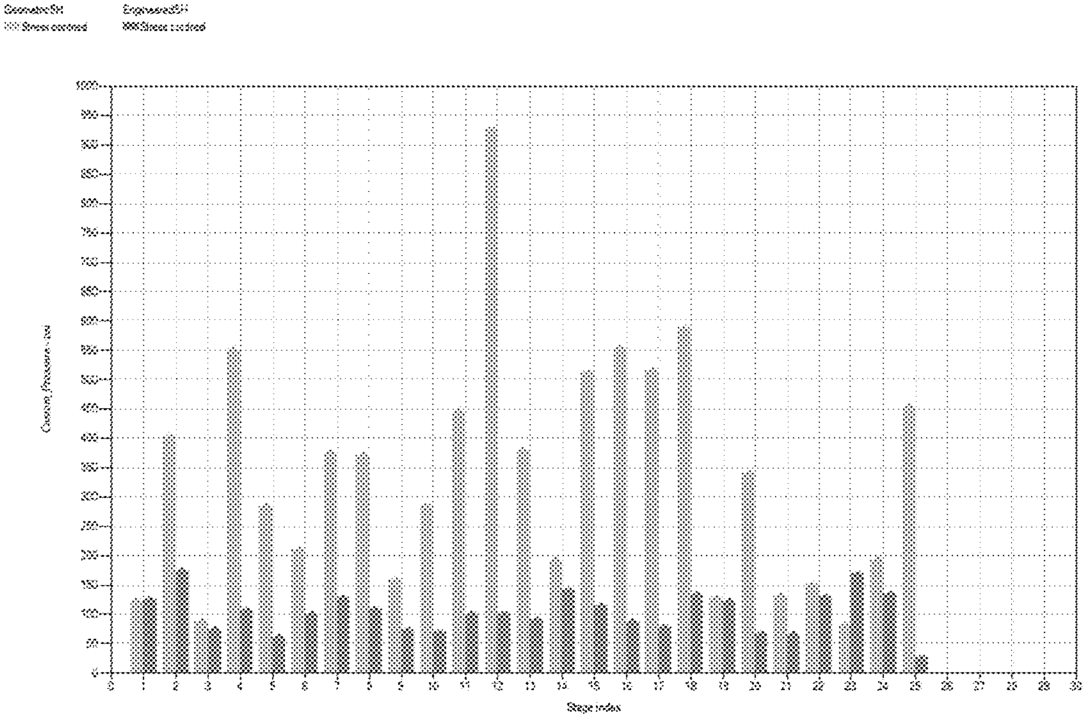

GeometricSH
▨ Stress control
EngineeredSH
▩ Stress control
Closure_Pressure - psi
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
Stage index

FIG. 5

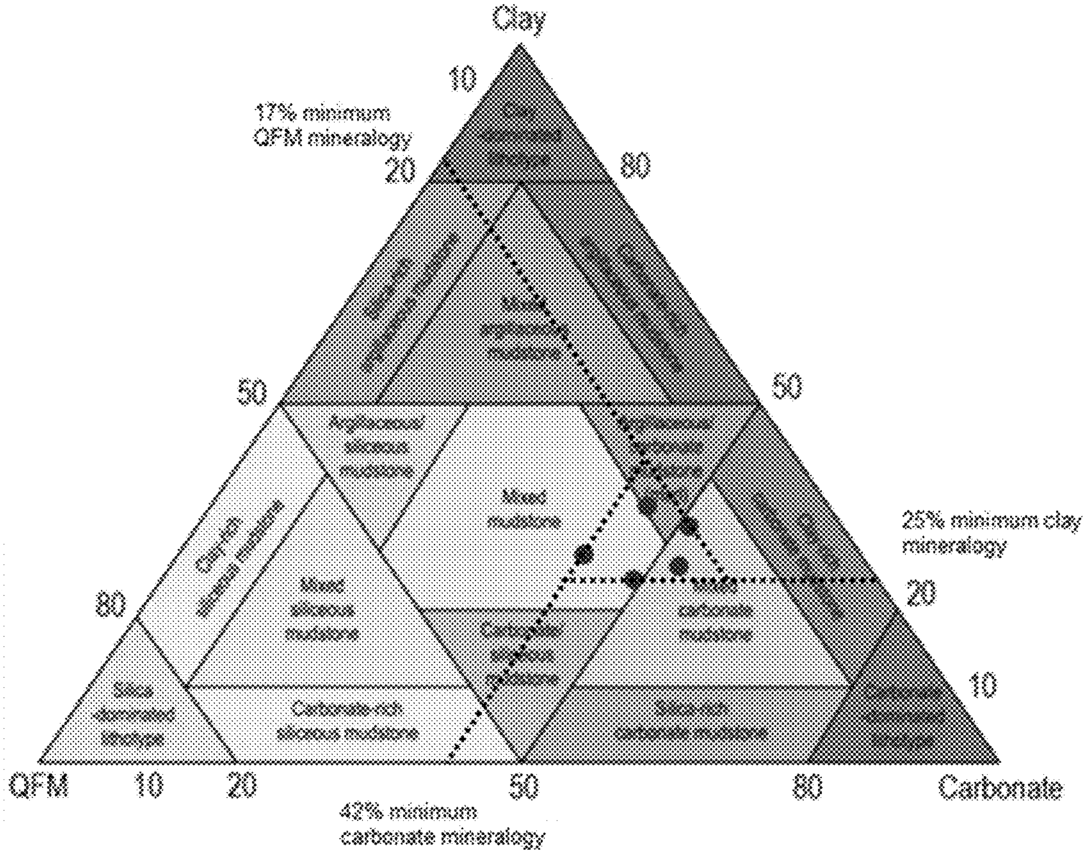

Clay
10
17% minimum
QFM mineralogy
20
80
Mixed
argillaceous
mudstone
50
50
Argillaceous
siliceous
mudstone
Mixed
mudstone
Clay-rich
siliceous mudstone
25% minimum clay
mineralogy
80
20
Mixed
siliceous
mudstone
carbonate
mudstone
Silica
dominated
lithotype
Carbonate-rich
siliceous mudstone
10
Silica-rich
carbonate mudstone
QFM
10
20
50
80
Carbonate
42% minimum
carbonate mineralogy

FIG. 6

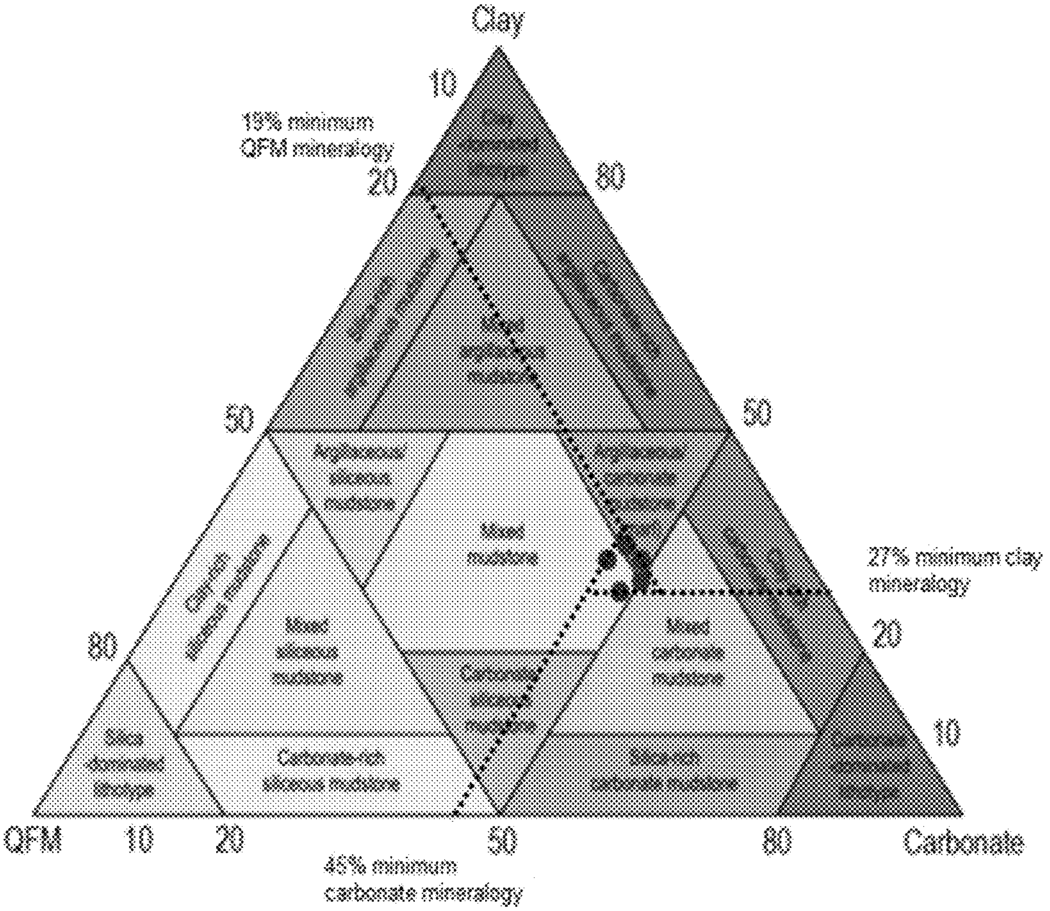

Clay
10
15% minimum
QFM mineralogy
20
80
50
50
Clay dominated lithotype
Mixed argillaceous mudstone
Argillaceous siliceous mudstone
Argillaceous carbonate mudstone
Mixed mudstone
27% minimum clay
mineralogy
Clay-rich siliceous mudstone
80
Mixed siliceous mudstone
Mixed carbonate mudstone
20
10
Silica dominated lithotype
Carbonate-rich siliceous mudstone
Silica-rich carbonate mudstone
Carbonate dominated lithotype
QFM
10
20
50
80
Carbonate
45% minimum
carbonate mineralogy

FIG. 7

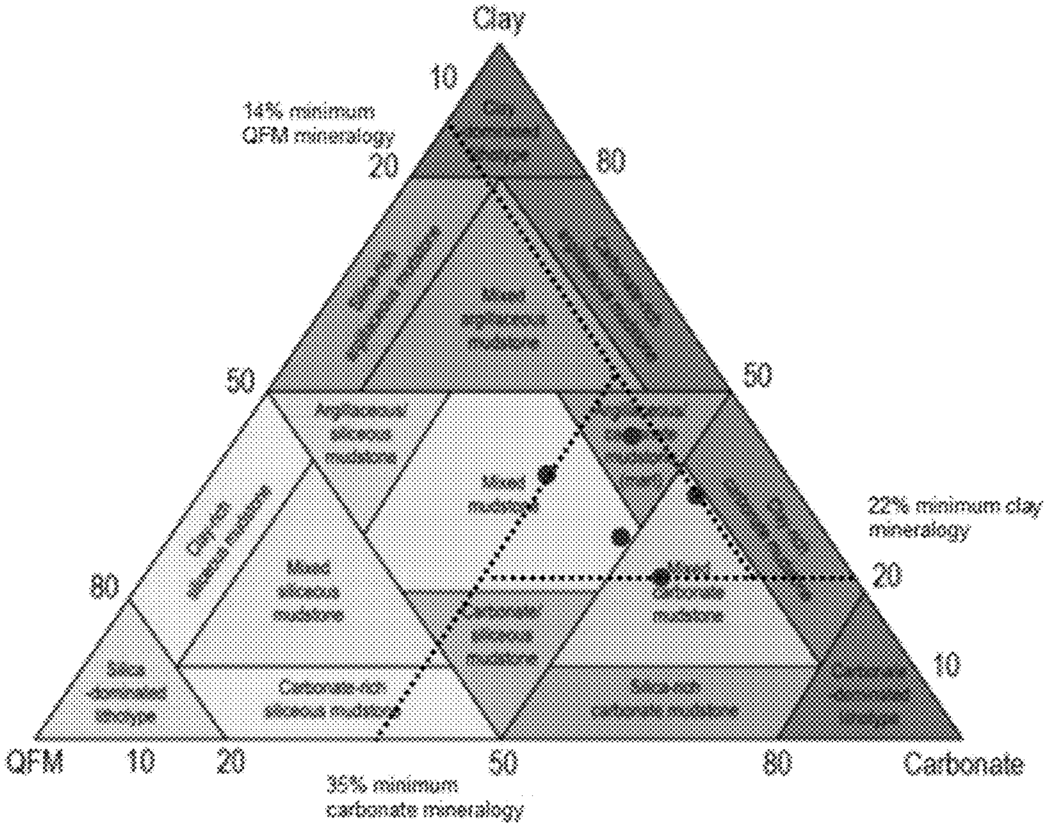

Clay
10
14% minimum
QFM mineralogy
20
80
Mixed
argillaceous
mudstone
50
50
Argillaceous
siliceous
mudstone
Mixed
mudstone
Clay-rich
siliceous mudstone
22% minimum clay
mineralogy
80
Mixed
siliceous
mudstone
Mixed
carbonate
mudstone
20
Carbonate
siliceous
mudstone
10
Silica
dominated
lithotype
Carbonate-rich
siliceous mudstone
Silica-rich
carbonate mudstone
QFM
10
20
50
80
Carbonate
35% minimum
carbonate mineralogy

FIG. 8

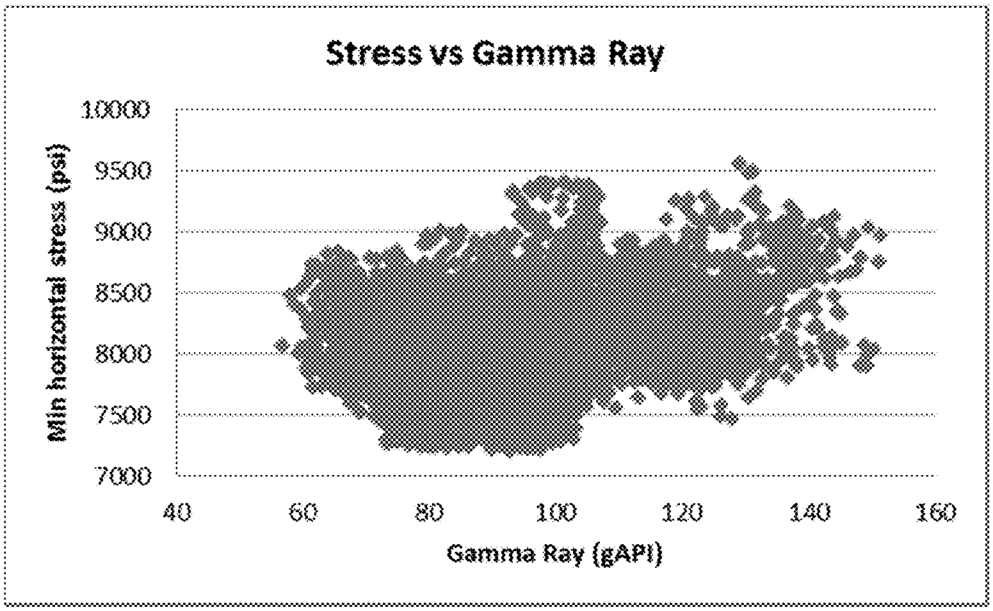

Stress vs Gamma Ray
Min horizontal stress (psi)
10000
9500
9000
8500
8000
7500
7000
40
60
80
100
120
140
160
Gamma Ray (gAPI)

FIG. 9

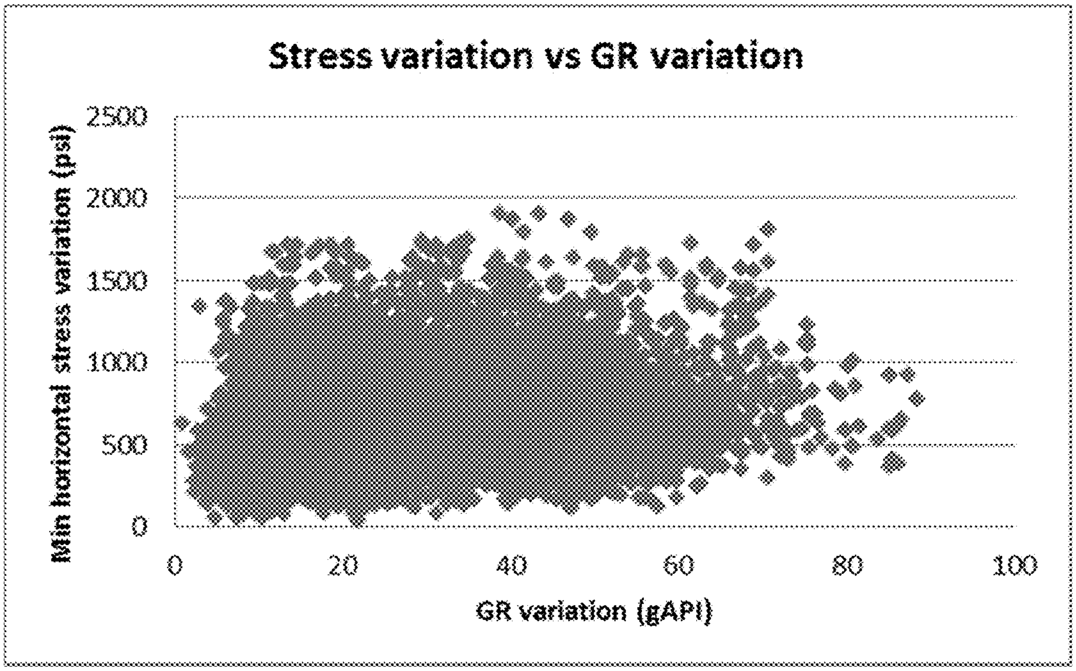

Stress variation vs GR variation
Min horizontal stress variation (psi)
2500
2000
1500
1000
500
0
0
20
40
60
80
100
GR variation (gAPI)

FIG. 10

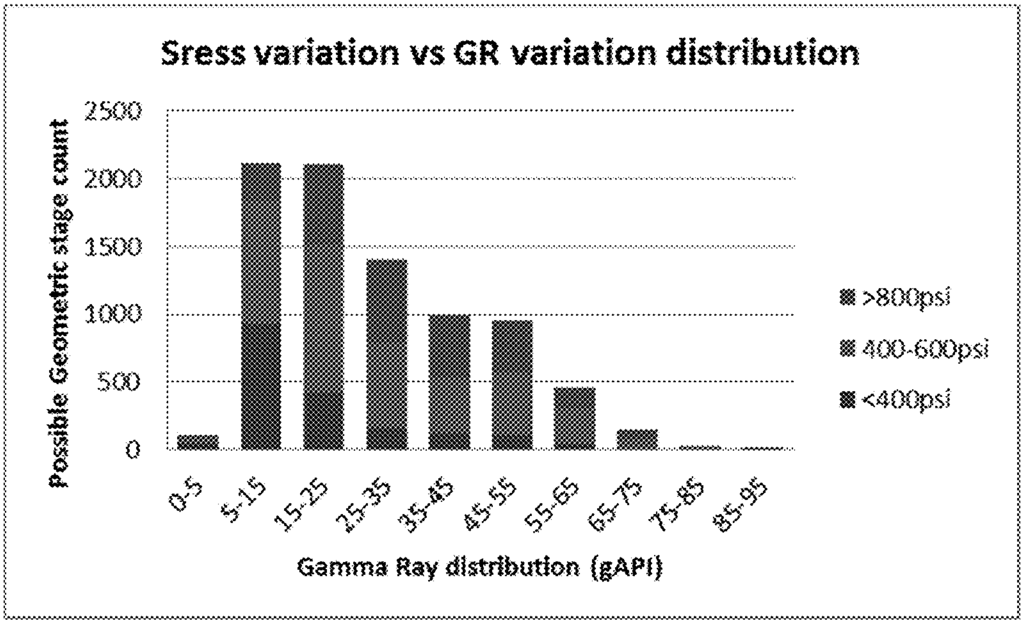

Sress variation vs GR variation distribution
Possible Geometric stage count
2500
2000
1500
1000
500
0
0-5
5-15
15-25
25-35
35-45
45-55
55-65
65-75
75-85
85-95
Gamma Ray distribution (gAPI)
▨ >800psi
▨ 400-600psi
▨ <400psi

FIG. 11

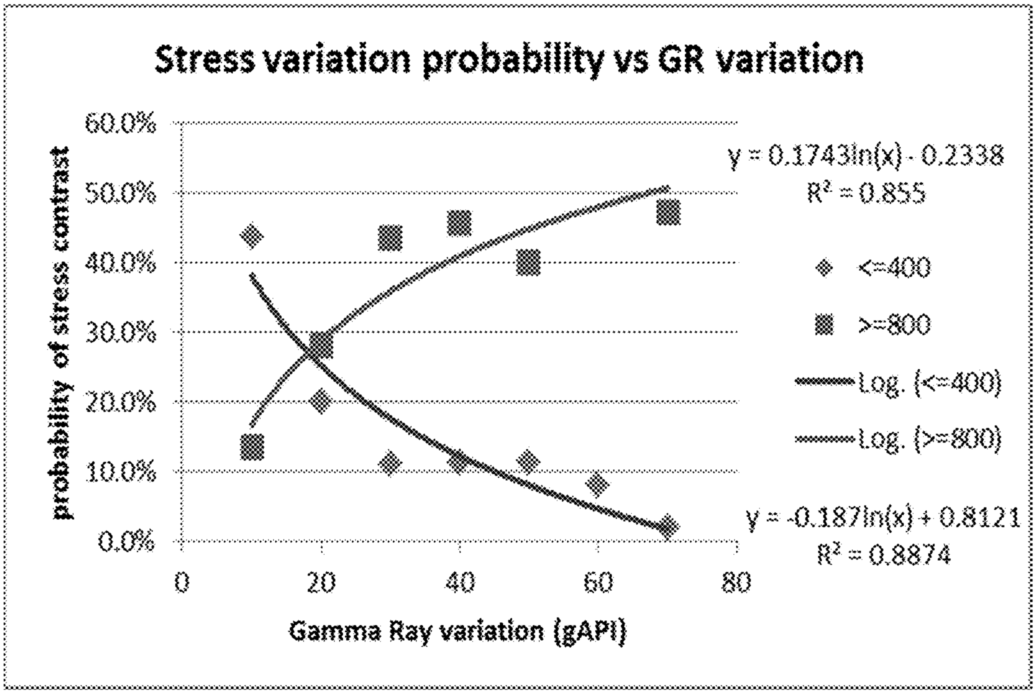

Stress variation probability vs GR variation
probability of stress contrast
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
0
20
40
60
80
Gamma Ray variation (gAPI)
y = 0.1743ln(x) - 0.2338
R² = 0.855
◆ <=400
■ >=800
Log. (<=400)
Log. (>=800)
y = -0.187ln(x) + 0.8121
R² = 0.8874

FIG. 12

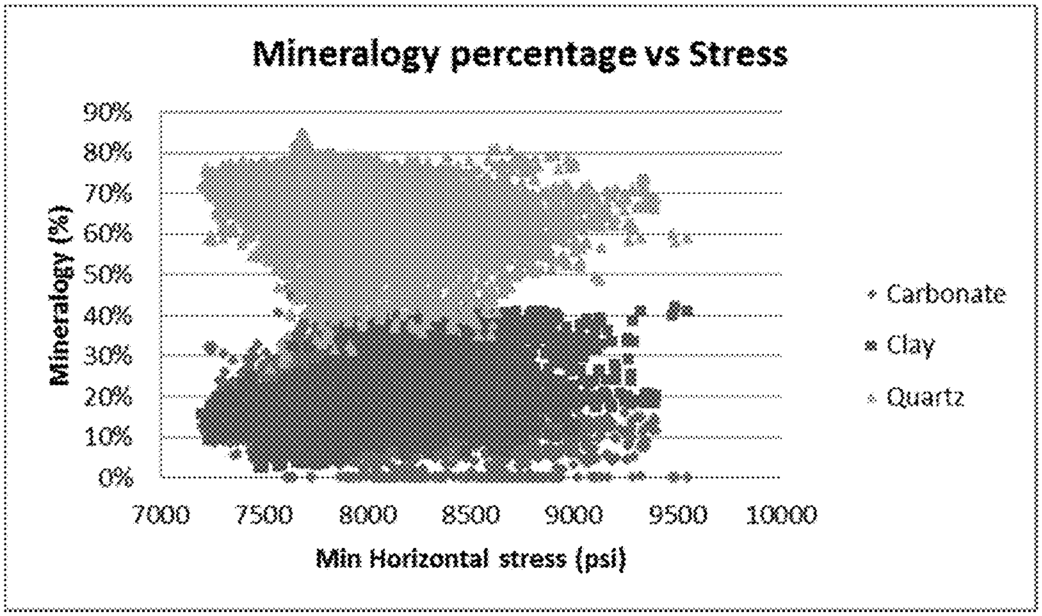

Mineralogy percentage vs Stress
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Mineralogy (%)
7000
7500
8000
8500
9000
9500
10000
Min Horizontal stress (psi)
Carbonate
Clay
Quartz

FIG. 13

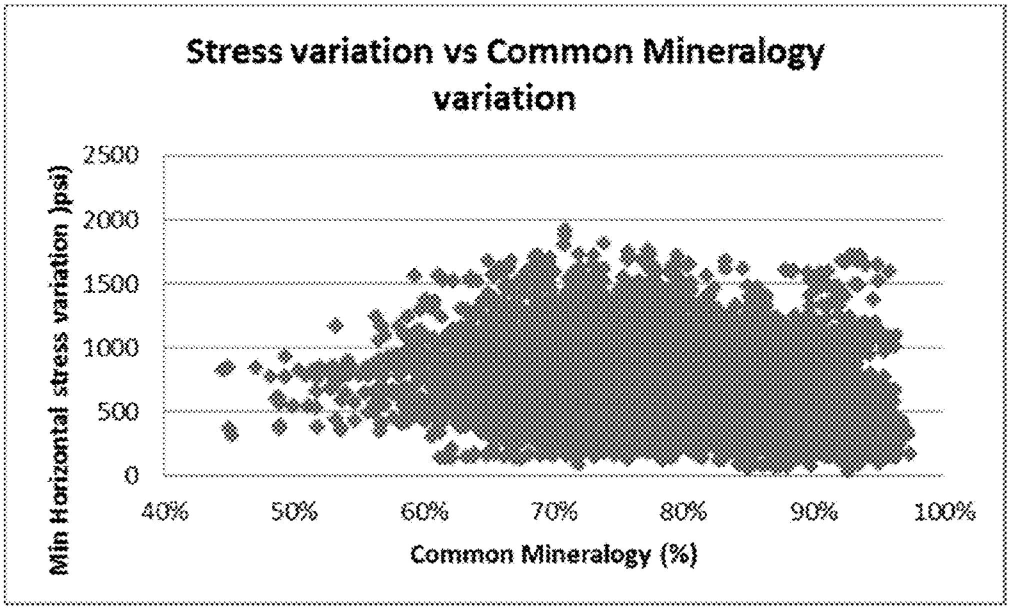

Stress variation vs Common Mineralogy variation
Min Horizontal stress variation)psi)
2500
2000
1500
1000
500
0
40%
50%
60%
70%
80%
90%
100%
Common Mineralogy (%)

FIG. 14

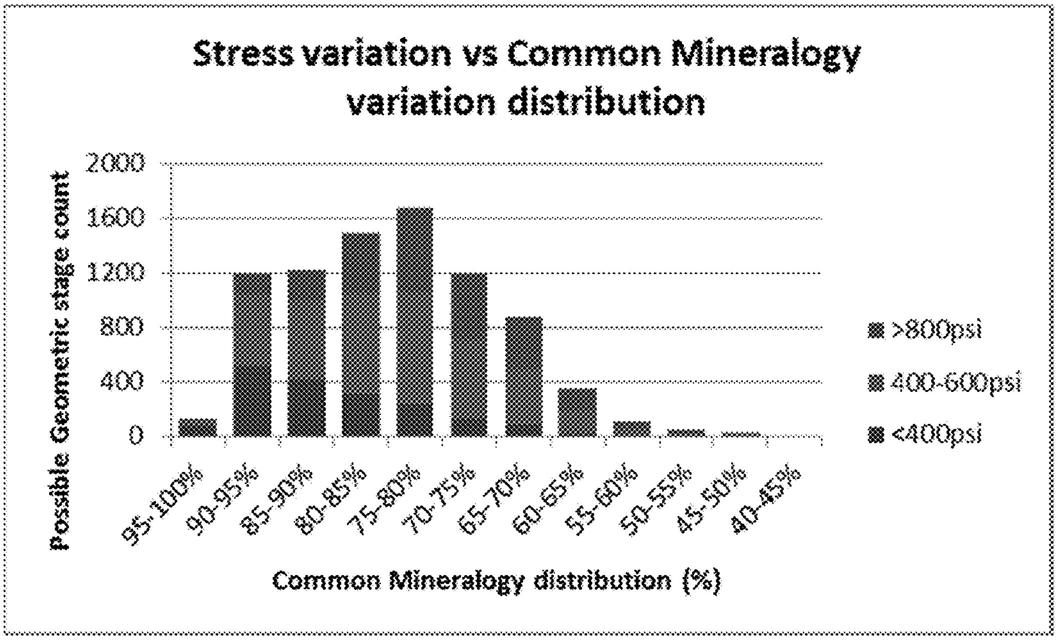

Stress variation vs Common Mineralogy variation distribution
2000
1600
1200
800
400
0
Possible Geometric stage count
95-100%
90-95%
85-90%
80-85%
75-80%
70-75%
65-70%
60-65%
55-60%
50-55%
45-50%
40-45%
Common Mineralogy distribution (%)
▨ >800psi
▨ 400-600psi
▨ <400psi

FIG. 15

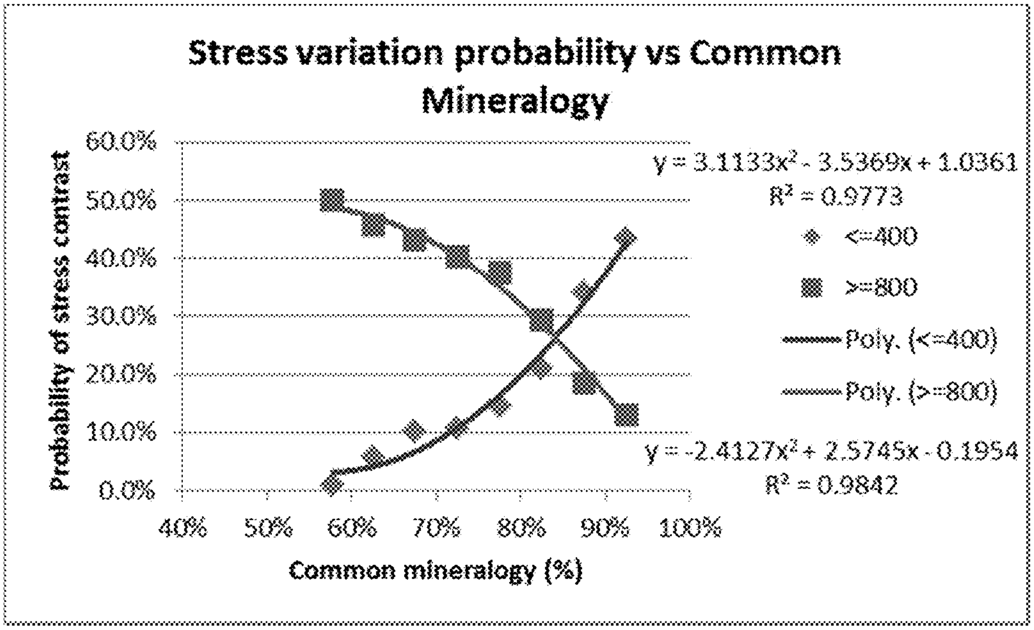
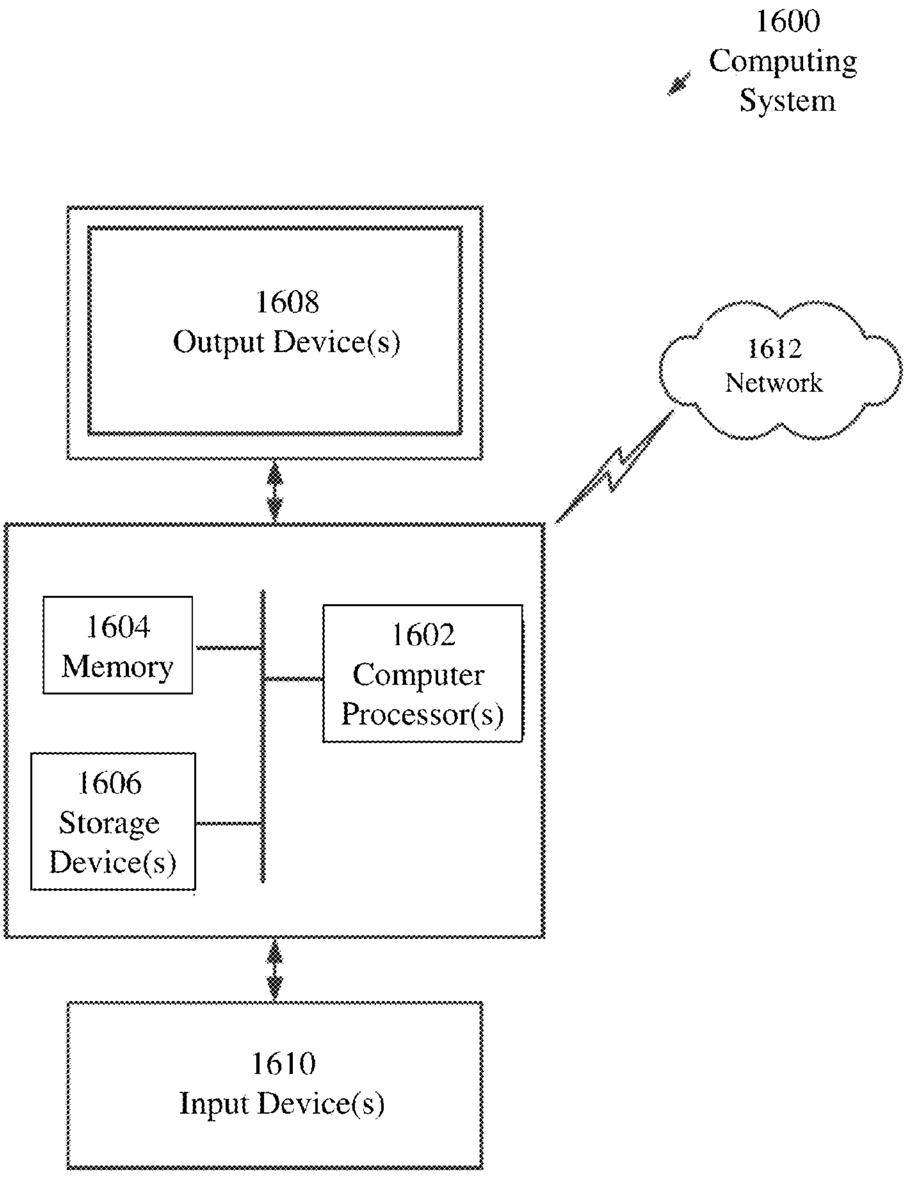

Stress variation probability vs Common Mineralogy
Probability of stress contrast
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
40%
50%
60%
70%
80%
90%
100%
Common mineralogy (%)
y = 3.1133x² - 3.5369x + 1.0361
R² = 0.9773
<=400
>=800
Poly. (<=400)
Poly. (>=800)
y = -2.4127x² + 2.5745x - 0.1954
R² = 0.9842

FIG. 16


1600
Computing
System
1608
Output Device(s)
1612
Network
1604
Memory
1602
Computer
Processor(s)
1606
Storage
Device(s)
1610
Input Device(s)

USE OF DRILLING DATA FOR ENGINEERED COMPLETIONS

PRIORITY

[0001] This application claims priority to U.S. Provisional Patent Application Ser. No. 62/245,395, filed on Oct. 23, 2015, and Ser. No. 62/269,396, filed on Dec. 18, 2015. Both applications are incorporated by reference herein.

BACKGROUND

[0002] Following the cessation of drilling operations, completions may be initiated in which downhole tubulars and equipment are installed to enable the safe and efficient production from an oil or gas well. During completions, sections of casing or pipe string may be placed into the wellbore to enhance wall strength and minimize the chances of collapse, burst, or tensile failure. Well casings of various sizes may be used, depending upon depth, desired hole size, and types of geological formations encountered. The casing and other tubulars may, in some instances, be stabilized and bonded in position using various physical and chemical techniques.

[0003] Following completions, stimulation operations may be conducted by initiating fractures or through the use of treatments such as acids and other chemicals that increase the porosity of the formation. Fracturing operations conducted in a subterranean formation may enhance the production of fluids by injecting pressurized fluids into the wellbore to induce hydraulic fractures and introducing flow channels that connecting isolated reservoirs. Fracturing fluids may deliver various chemical additives and proppant particulates into the formation during fracture extension. Following the injection of fracture fluids, introduced proppants may prevent fracture closure as applied pressure decreases below the formation fracture pressure. The propped open fractures then allow fluids to flow from the formation through the proppant pack to the production wellbore.

SUMMARY

[0004] This summary is provided to introduce a selection of concepts that are described further below in the detailed description. This summary is not intended to identify key or essential features of the claimed subject matter, nor is it intended to be used as an aid in limiting the scope of the claimed subject matter.

[0005] In one aspect, embodiments of the present disclosure are directed to methods that may include applying a correlation between the probability of stress variations in a first well and variations in drilling data obtained from the first well to drilling data obtained from one or more additional wells; calculating a proportion of high stress and low stress contrast stages within the one or more additional wells; and creating one or more synthetic stress profiles for various completion techniques based on the calculated proportion of high stress and low stress contrast stages within the one or more additional wells; and using the one or more synthetic stress profiles to create a synthetic stress log for a geometric completion (GC) and an engineered completion (EC).

[0006] In another aspect, embodiments of the present disclosure are directed to methods that may include obtaining drilling data from one or more wells; calculating a proportion of high stress and low stress contrast stages within the one or more additional wells; and creating one or more synthetic stress profiles for various completion techniques based on the calculated proportion of high stress and low stress contrast stages within the one or more wells.

[0007] Other aspects and advantages of the disclosure will be apparent from the following description and the appended claims.

BRIEF DESCRIPTION OF FIGURES

[0008] FIG. **1** is a graphical depiction of a production forecast comparison between engineered completions and geometric completions in a well in which formation stress does not vary significantly alone the lateral.

[0009] FIG. **2** is a graphical depiction of a production forecast comparison between engineered completions and geometric completions in a well in which formation stress varies significantly alone the lateral.

[0010] FIG. **3** is a flow diagram depicting a completions workflow in accordance with embodiments of the present disclosure.

[0011] FIG. **4** is a graphical depiction showing stage stress contrast between geometric completions and engineered completions in accordance with embodiments of the present disclosure.

[0012] FIG. **5** is an illustration depicting the common mineralogy concept applied to five clusters of different mineralogy in accordance with embodiments of the present disclosure.

[0013] FIG. **6** is an illustration depicting high common mineralogy in which five clusters formed in similar rock in accordance with embodiments of the present disclosure.

[0014] FIG. **7** is an illustration depicting an example of low common mineralogy in which five clusters are present in very different rocks.

[0015] FIG. **8** is a graphical depiction of raw data minimum horizontal stress as a function of gamma ray response in accordance with embodiments of the present disclosure.

[0016] FIG. **9** is a graphical depiction of stress variation versus gamma ray variation in accordance with embodiments of the present disclosure.

[0017] FIG. **10** is a histogram depicting counts of cluster groups with high, medium, and low stress variation as a function of distribution of gamma ray variation in accordance with embodiments of the present disclosure.

[0018] FIG. **11** is a graphical depiction of stress variation probability as a function of gamma ray variation in accordance with embodiments of the present disclosure.

[0019] FIG. **12** is a graphical depiction showing raw data mineralogy as a function of minimum horizontal stress in accordance with embodiments of the present disclosure.

[0020] FIG. **13** is a graphical depiction of stress variation as a function of common mineralogy variation in accordance with embodiments of the present disclosure.

[0021] FIG. **14** is a histogram showing stress variation as a function of common mineralogy variation distribution in accordance with embodiments of the present disclosure.

[0022] FIG. **15** is a graphical depiction of stress variation probability as a function of common mineralogy in accordance with embodiments of the present disclosure.

[0023] FIG. **16** is an illustration showing a computer system in accordance with embodiments of the present disclosure.

DETAILED DESCRIPTION

[0024] In one aspect, methods in accordance with embodiments disclosed here may be directed to completion methods that enable users to compute an estimated magnitude of stress variation within a given wellbore from various data sources, including drilling data. In another aspect, methods in accordance with the present disclosure may involve a comparison between outcomes of geometric completions (GC) and engineered completions (EC) on the basis of drilling data for a series of wells in a given formation. Further, in some embodiments, methods may be used to rank a series of wells and flag which wells in are candidates for additional logging operations and EC when considering a number of factors such as the degree of possible production enhancement and economic feasibility.

[0025] In one or more embodiments, methods in accordance with the present disclosure may use statistical analysis to determine variations of formation stress between zones within a well obtained from drilling data to aid in the design of completions. Analysis of formation stress may be a factor considered in some completion operations to avoid the placement of clusters in wellbore zones of high stress contrast. Completion designs may seek to minimize the placement of clusters in zones having high contrast, because such placements may be associated with undesirable effects such as the disemboguing of various treatment fluids into high permeability zones during stimulation, and reduced production from poorly stimulated zones.

[0026] In one or more embodiments, methods in accordance with the present disclosure may be used to verify the quality of the formation prior to geometric cluster placement and/or inform the design of stimulation operations to enable engineered cluster placement to minimize the degree of stress contrast between perforation clusters in a given stage and ensure that all clusters will take part of the fracturing treatment, stimulation, and production. For example, stress contrast between clusters that is below 300-400 psi, regarded as "low stress contrast," may result in the stimulation of all clusters in a given stage. On the other hand, "high stress contrast" between clusters, in which the stress contrast between clusters is above 700-800 psi, may result in 20-40% of the clusters not being stimulated due to the initiation of low stress clusters at earlier time points during treatment, stunting the growth of (and subsequent production from) higher stress clusters.

[0027] Methods in accordance with the present disclosure may also use different data types to establish and correlate the probable amplitude of stress contrasts and the ability to create synthetic stimulation designs that can be compared in terms of production and economic value. In some embodiments, drilling data may be used to estimate variability of the stress along a well or in a lateral, which may enable a user to determine whether additional well logging should be employed for EC.

[0028] During completions, the location of stages and perforation clusters in cased-hole horizontal wells may be defined in a number of ways, including GC and EC. GC design relies on standardized and regular stage lengths, cluster number and spacing along the depth of the well. GC designs may be advantageous in terms of planning time and in formations that have a degree of homogeneity in composition. When placing clusters in a rock of similar stress, the low stress contrast between clusters may allow treatment of multiple zones, because there is less risk of unequal pressure and treatment fluid delivery among the zones, which may result in stimulation that is approximately homogeneous. However, during completions in a well containing low and high permeability zones, fractures in the higher permeability zones may appear first and divert the treatment fluids from lower permeability zones, with the result that GC may generate a number of clusters that do not contribute to production due to uneven stimulation and other issues such as insufficient proppant placement and uncontrolled fracture extension.

[0029] In contrast, EC design may be characterized as a completions technique in which the process may begin by selecting a stage length, number of clusters per stage, and cluster spacing. In some cases, EC designs may then adjust the specific length of each stage, number of clusters per stage, and cluster spacing, are later adjusted on the basis of downhole logs and formation measurements to minimize the presence of clusters in non-optimal or problematic conditions in a selected stage. As an example, EC may modify cluster placement to avoid cluster placement occurs in zones having an undesirable degree of stress contrast, resulting in wells having lower average stress contrast.

[0030] EC designs in accordance with the present disclosure may maximize production by maximizing the number of stimulated clusters. As an example, production log measurements in the Eagle Ford from wellbores that were stimulated using GC indicate that up to 30-50% of all perforation clusters did not contribute to production. Conversely, in wells completed by an EC design, only 15-25% of the perforation clusters were unproductive, which resulted in a 10-30% productivity increase over the comparative GC design.

[0031] However, the economic value of an EC design may vary from well to well. In wells placed in marginal reservoirs, production increases attributed to EC may be negligible in comparison to the additional costs of logging the well. Similarly, in wells in which stress does not vary significantly along the lateral, the incremental production increase from the use of an EC design may not offset increased logging costs over the GC design base case. With particular respect to FIG. **1**, model production of hydrocarbons over time is shown for a low stress contrast well when completed using GC and EC, respectively. As demonstrated, the production differences between the two techniques do not vary to any great degree, which suggests that GC is the more economical choice for this particular well.

[0032] On the other hand, in a well where stress varies significantly along the lateral in a medium-high quality reservoir, such as the scenario presented in FIG. **2**, production increases from logging and EC design will compensate for the initial investment over a GC design within an acceptable timeframe. Moreover, completing all wells with the same completions approach may not be optimal either, as each of the completions techniques have strengths and weaknesses. In such cases, wells may be ranked and flagged for potential development using EC, while the remaining wells are produced using GC.

[0033] During completions, operators may drill vertical pilot holes and obtain logs to produce a "layer cake" reservoir model that may be propagated horizontally based on seismic data to output layer tops. Once a reservoir model is established, the horizontal well trajectory may be located in the model for stimulation simulation and comparison between GC and EC design. However, building reservoir models from pilot hole logs may involve high costs in terms of personnel and time.

[0034] Methods in accordance with the present disclosure may develop correlations between data obtained from a pilot well and determinations of stress contrasts in the pilot well. The correlations obtained from the pilot well may then be combined with drilling data obtained in one or more subsequent wells to generate information regarding the formation quality, stress variations and contrasts. In some embodiments, correlations generated from the pilot well may be used to evaluate drilling data and to create a synthetic stress log using various probabilistic techniques. Although direct correlations between stress and drilling data may be unreliable in some cases because no single parameter dominates stress determination, clusters located zones of a formation having similar rock composition and characteristics may have low stress contrast, which may allow the placement of additional clusters. Conversely, the placement of clusters in zones having dissimilar composition and rock types, may require engineered completions to avoid creating high stress contrast between clusters, which may result in treatment fluid diversion and reduced efficiency during production.

[0035] Factors that may be used to determine formation stress may include the mineral composition of the formation, which may be studied using known techniques such as gamma ray (GR) logs. In some embodiments, information obtained during drilling may also be used as a proxy to study formation quality. In particular, changes during drilling such as weight on bit, rotations per minute (RPM), torque, rate of penetration (ROP), and the like may be translated into a description of the types of rock encountered within the formation. For example, changes in drilling speed at constant power may be an indication of formation heterogeneity and the presence of zones of contrasting stress.

[0036] Methods in accordance with the present disclosure may enable comparison between GC and EC on a fast time scales, such as one well per hour in some embodiments. Further, synthetic stress logs generated from drilling data may be used to evaluate the economic feasibility of various completion methods in some embodiments. In some embodiments, methods may enable multiple wells to be screened in batch processing. Further, methods in accordance with the present disclosure may allow wells to be analyzed in real-time analysis as a well is being drilled in some embodiments.

[0037] With particular respect to FIG. **3** an embodiment of a reservoir evaluation workflow is shown. Methods in accordance with the present disclosure may include establishing correlations between probability of variations of stress and variations of drilling data in wells for which a stress log is available at **302**. Applying correlations established in **302** to wells within the same or similar formation for which the only data available is drilling data, and calculating the overall proportion of high and low contrast stages.

[0038] In one or more embodiments, methods in accordance with the present disclosure may estimate which wells in a given reservoir may exhibit enhanced production through EC without the added expense of logging the wells to generate logs used to determine post-stimulation wellbore productivity. In order to evaluate the outcomes of GC and EC, synthetic stress profiles for each technique are developed at **306** based upon a calculated proportion of high and low stress contrast stages. The generated synthetic stress profiles for each completion technique may then be used to create synthetic stress logs at **308** in some embodiments, which may allow simulation of both GC and EC designs, including the generation of production forecasts and economic estimates. Based on the synthetic stress information obtained, wells may be ranked on the basis of various qualities at **310**. For example, wells may be ranked and, depending on economic feasibility, a subset may be flagged for further data acquisition and completion using EC techniques.

[0039] Methods in accordance with the present disclosure may be applied to drilling data collected from one or more wells, which may allow a user to rank the wells in terms of production and/or profitability. In one or more embodiments, a large population of wells may be analyzed using correlation and ranked by order of average stress contrast, wells containing the areas of least stress contrast may then be selected as initial candidates to lower costs associated with additional wellbore analysis and remedial efforts during stimulation and production. For example, methods in accordance with the present disclosure may utilize data obtained from gamma ray (GR) measurements acquired during or following drilling operations. In some embodiments, GR data may be used to select wells having a minimal GR contrast that may indicate minimal stress contrast between zones. Other factors that may be used to rank wells include drilling quality, dogleg severity for horizontal well sections, and forms of drilling data that exhibit variations when encountering differing types of rock.

[0040] In one or more embodiments, correlations established for one or more wells from which both drilling data and stress log are available, may be applied on neighboring wells for which only drilling data is available to create synthetic stimulation designs, such as GC and EC, that may be compared in terms of production to evaluate the incremental economic value of the EC design and associated data gathering. In some embodiments, methods in accordance with the present disclosure may enable a user to evaluate wells traversing formations similar to a pilot well during the drilling phase as data is gathered to produce a real-time decision of whether to mobilize logging acquisition based on a number of factors including economic analyses. Methods in accordance with the present disclosure may also be used on large groups of wells that are cased-cemented and are waiting to be stimulated to determine whether all or a subset of wellbore are a candidate for logging characterization and EC design.

[0041] Methods in accordance with the present disclosure may use drilling data to determine the stress contrast within the wellbore. Stress quantification within a formation depends on a number of parameters such as vertical depth, overburden, mechanical properties such as Young's modulus, Poisson's ratio, rock structure such as lamination, planes of weakness, and the like, pore pressure and tectonic forces. In some embodiments stress quantification may be determined in accordance to Eq. 1, where σ is the minimum horizontal stress, P_P is the pore pressure, υ is the Poisson's ratio, E is the Young's modulus, and e is the uniaxial strain.

$$\sigma_{x(Hmin)} - P_{p(H)} = \frac{v}{1-v}[\sigma_v - P_{p(V)}] + \frac{E}{1-v^2}(e_x + ve_y) \tag{1}$$

[0042] In one or more embodiments, a histogram of well stress variation, as determined from stress correlations with drilling data obtained from the well, may be built, and the shape of the histogram may be used to interpret the level of heterogeneity between zones in a given formation based on the completion method selected. With particular respect to FIG. **4**, an example of stage stress contrast histogram between GC and EC designs is shown. For the wells surveyed, the average stress contrast for EC design was 125 psi compared to an average stress contrast of 525 psi for GC design.

[0043] Workflow Outline

[0044] In one or more embodiments, methods in accordance with the present disclosure may include processing drilling data such as measurement-while-drilling (MWD) data, logging-while-drilling (LWD) data, logging interpretations, drilling parameters, wellbore trajectory, and cuttings analysis in a manner that generate probabilities of high and low stress contrast for sets of clusters. These correlations are based on the principle that variation of drilling data is correlated to variation in the rock, which may then be correlated to stress contrast. For example, GR logs obtained during drilling may be used to establish a stress histogram for a given well to determine formation heterogeneity. In formation zones having low differential GR response, then there may be low heterogeneity within the formation. Conversely, high differential GR response may indicate regions of high heterogeneity in the formation.

[0045] Once correlations are established on a well between drilling data, and stress logs are available, these correlations can be used on near-by wells for which only drilling data is available to create synthetic GC and EC design that can be compared to evaluate the economic value of the EC design and associated data gathering. This method allows for wells to be evaluated during the drilling phase as data is gathered to produce a real-time decision that triggers the mobilization of logging tools or not based on the economic analysis. This process can also be used on large groups of wells that are cased-cemented and are waiting to be stimulated. Wells among such a large group that have the potential to economically benefit the most from an EC design are flagged for cased-hole logs and EC design.

[0046] Methods in accordance with the present disclosure may use the correlation between the probability of stress variations in a well and variations in drilling data obtained from a number of sources, which may then be applied to determine correlations in neighboring wells, or wells in similar formations, from obtained drilling data. In one or more embodiments, variations in drilling data may be derived from a number of sources including the range of minimum and maximum data values for each data set obtained from clusters within a well; the common mineralogy for each data set obtained from clusters within a well; and statistical processing of each data set obtained from clusters within a well. In the following sections exemplary types of drilling data and processing methods are discussed in turn.

[0047] Drilling Data

[0048] In one or more embodiments, drilling data may be used to generate information that may be used to correlate rock composition and type, to stress data for a given section or interval of a well to develop information regarding the presence of stress zones. In some embodiments, drilling data may be obtained from gamma ray measurements, such as gamma ray (GR), spectral gamma ray (SGR), mechanical specific energy (MSE), or thermal conductivity, which may be collected using LWD or other logging techniques applied following removal of a drill string.

[0049] In one or more embodiments, secondary processing such as rock typing may also be used to determine rock composition and type. In some embodiments, methods in accordance with the present disclosure may also utilize various drilling parameters such as rate-of-penetration (ROP), weight-on-bit (WOB), torque or rotations-per-minute (RPM) measured during drilling as well as ratios of these parameter such as rate of penetration per rotation (ROP/RPM). Drilling data in accordance with the present disclosure may also include total mineralogical composition such as percentage by volume or weight, measured from cuttings or derived from various wellbore logs. Methods in accordance with the present disclosure may also utilize wellbore trajectory data such as measured depth, vertical depth as well as their derivation such as azimuth, wellbore deviation, and dog leg severity (DLS).

[0050] Concept of Common Mineralogy

[0051] In one or more embodiments, common mineralogy (CM) may be used to classify rocks within a surveyed interval or series of clusters. In some embodiments, CM may indicate the various rock types in a given interval, and may be used to determine the stress contrast between differing types of rocks. CM may also be combined with drilling data in some embodiments to generate a synthetic stress log. CM is a measure of the anisotropy between different rocks associated with specific single-stage clusters depth. According to this approach, mineralogical compositions by weight or volume are simplified into 3 main mineral groups: carbonates; clays; and quartz, feldspar, and mica (QFM). Once normalized to 100%, the minimum percentages for each mineral group are summed into what is defined as the common mineralogy. Common mineralogy may then be calculated by determining the sum total of the minimum mineralogy percent among the total number of clusters surveyed. In the cases in which the common minerology is close to 100%, all surveyed clusters contain rock composition that are homogenous or approximately homogenous. On the other hand, if the common mineralogy is close to 0%, all surveyed clusters contain rock compositions that are distinct.

[0052] In one or more embodiments, common mineralogy may be calculated using a ternary diagraph, in which the three apexes represent the dry-weight components clay, carbonate, and QFM. FIGS. **5**-**7** provide a graphic illustration of the common mineralogy concept. With particular respect to FIG. **5**, an illustration of the common mineralogy concept is shown in which the calculation is applied to five clusters within a wellbore and having a common mineralogy of 84%. With particular respect to FIG. **6**, an example is shown for five clusters measured containing high common mineralogy of 91%, which indicates the presence of similar rock types. With particular respect to FIG. **7**, another ternary plot is shown for five analyzed clusters, and indicating a common mineralogy of 71%.

[0053] Data Processing

[0054] Methods in accordance with the present disclosure may utilize data to establish correlations between drilling data and stress contrasts within the wellbore. In some embodiments, correlations may be established by obtaining drilling data and creating data sets that include data points and may be used to establish spatial relationships between points in the data set. For example, data sets may be characterized as containing A data points, B feet from each other, with A being the GC design number of clusters per stage and B being the GC design cluster spacing.

[0055] Drilling data processing in accordance with the present disclosure may include obtaining variations of the drilling data, which may be derived from (1) the range of maximum and minimum data values for each data set of A clusters, (2) the common mineralogy for each data set of A clusters, and by (3) using statistical processing of each data set, which may include the determination of one or more of average, median, skew, standard deviation, variance, and the like.

[0056] Drilling data processing in accordance with the present disclosure may also include establishing the distribution of stress variation, such as high and low stress contrast thresholds, as a function of data variation. In some embodiments, drill data processing may generate two data sets, including (1) the probability of high stress contrast as a function of data variation value, and (2) the probability of low stress contrast as a function of data variation value. Data processing may involve the use of linear, polynomial, logarithmic or exponential trend lines that may be used to extract equations that become the correlations used for the second part of the workflow.

[0057] Application of Stress Correlations to Drilling Data

[0058] Methods in accordance with the present disclosure may enable a user to design completions in scenarios in which there is only drilling data available, without obtaining additional wellbore logs. In some embodiments, establishing correlations may include a step of calculating variation of the drilling data sets. Methods of completion design may also involve include the step of calculating the probabilities of high and low stage stress contrast. In some embodiments, stress probability calculation may involve summing both the high and low probabilities for all possible clusters and dividing these number by the total number of possible clusters to obtain the well-level distribution of high and low stress contrast stages.

[0059] Creation of Synthetic Well Models for Completions Designs

[0060] In one or more embodiments, completions design techniques in accordance with the present disclosure may include the creation of one or more synthetic well models for use in subsequent processing steps. Methods of creating a synthetic model for completion design may include a processing step in which multiple stress logs are created using a selected completions technique, such as GC or EC, and assigning a stress level to each perforation cluster based on each stage stress contrast established from a stress contrast distribution generated for a given wellbore.

[0061] In some embodiments, synthetic well models may be used to create a stress contrast distribution along the length of the well using various processing techniques. Processing techniques that may be applied to a synthetic well model in accordance with the present disclosure may include creating a stress contrast distribution along the wellbore. Stress contrast distributions may be generated by aggregating the total number of stages, applying the distribution of high and low stress contrast stages, and distributing the stages on the basis of high and medium stress contrast, and on the basis of the drilling data variation along the wellbore.

[0062] In one or more embodiments, stress contrast correlations may be performed on one or more wellbores based upon information obtained during drilling. In some embodiments, zones of stress contrast may provide an operator with an estimate of how many clusters may experience high contrast using statistical model as compared to other model types such as geometric models. In some embodiments, methods of creating as synthetic model for completion design may include a step of simulation each completion design and modeling production forecasts to compute the value of the incremental production and evaluate the economic value of the selected completions approach and its associated incremental data acquisition.

[0063] Flagging of Candidate Well

[0064] In one or more embodiments, wells for which the incremental production generated by the EC approach makes the incremental data acquisition economical are flagged for logging. In some embodiments, flagging may be done while the well is being drilled, such as when the well is 50% drilled. In some embodiments, groups of wells that have been or are pending stimulation, EC in accordance with the present disclosure may be applied to identify and flag potential wells for production enhancement.

[0065] In one or more embodiments, software packages that generate visual log measurements such as the MANGROVE™ plugin for PETREL™, all of which are available from Schlumberger Technology Corporation may be used during stimulation planning to minimize stress contrast between stages.

Example

[0066] In the following examples, a method of completion design is performed in accordance with the present disclosure. Methods discussed below begin by building a correlation between GR log response and stress obtained from the wellbore. Following the drilling of a well, drilling data in the form of a GR log (measured in GR API units) is compared to stress measurements for the well. With particular respect to FIG. **8**, plotting the raw data of minimum horizontal stress as a function of the GR log response shows little to no correlation. However, with particular respect to FIG. **9**, a plot of the variation of horizontal stress for stages at multiple cluster depths as a function of GR variation shows low correlation again, but exhibits notable features, such as low stress contrast for low GR variation and high stress contrast in high GR variation. GR variation in FIG. **9** was calculated as the difference between the maximum and minimum measured GR vales for a selected set of cluster depths. Stress variation was calculated from the difference of the maximum recorded stress and the minimum recorded stress for the corresponding cluster depths.

[0067] The stress variation in the pilot well clusters was also evaluated by creating a histogram of stress variation for possible geometric stages sorted by the gamma ray distribution. With particular respect to FIG. **10**, a histogram depicting counts of cluster groups with high, medium, and low stress variation as a function of distribution of gamma ray variation is shown. The probability of stress contrast for high (>800 psi) and low (<400 psi) stresses in the well may also be plotted as a function of GR variation. With particular respect to FIG. **11**, the associated trend-lines for high and low stress contrast each show a good correlation of $R^2>0.8$.

[0068] Next, the example data was processed and compared as stress as a function of common mineralogy. With particular respect to FIG. **12**, a graphical depiction showing minimum horizontal stress as a function of raw data mineralogy, which appears to indicate a lack of correlation between mineral types. With particular respect to FIG. **13**, the data is presented as the variation of stress as a function of common mineralogy, which shows low correlation, but is notable in that the low stress contrast is seen in high common mineralogy variation, while high stress contrast corresponds to low common mineralogy variation. With particular respect to FIG. **14**, the data is also presented as a histogram showing high, medium, and low stress variation as a function of common mineralogy variation distribution. The probability of stress contrast for high (>800 psi) and low (<400 psi) stresses in the well may also be plotted as a function of common mineralogy. With particular respect to FIG. **15**, the associated trend-lines for high and low stress contrast each show a good correlation of $R^2>0.8$.

[0069] Embodiments of the present disclosure may be implemented on a computing system. Any combination of mobile, desktop, server, embedded, or other types of hardware may be used. For example, as shown in FIG. **16**, the computing system (**1600**) may include one or more computer processor(s) (**1602**), associated memory (**1604**) (e.g., random access memory (RAM), cache memory, flash memory, etc.), one or more storage device(s) (**1606**) (e.g., a hard disk, an optical drive such as a compact disk (CD) drive or digital versatile disk (DVD) drive, a flash memory stick, etc.), and numerous other elements and functionalities. The computer processor(s) (**1602**) may be an integrated circuit for processing instructions. For example, the computer processor(s) may be one or more cores, or micro-cores of a processor. The computing system (**1600**) may also include one or more input device(s) (**1610**), such as a touchscreen, keyboard, mouse, microphone, touchpad, electronic pen, or any other type of input device. Further, the computing system (**1600**) may include one or more output device(s) (**1608**), such as a screen (e.g., a liquid crystal display (LCD), a plasma display, touchscreen, cathode ray tube (CRT) monitor, projector, or other display device), a printer, external storage, or any other output device. One or more of the output device(s) may be the same or different from the input device(s). The computing system (**1600**) may be connected to a network (**1612**) (e.g., a local area network (LAN), a wide area network (WAN) such as the Internet, mobile network, or any other type of network) via a network interface connection (not shown). The input and output device(s) may be locally or remotely (e.g., via the network (**1612**)) connected to the computer processor(s) (**1602**), memory (**1604**), and storage device(s) (**1606**). Many different types of computing systems exist, and the aforementioned input and output device(s) may take other forms.

[0070] Software instructions in the form of computer readable program code to perform embodiments of the disclosure may be stored, in whole or in part, temporarily or permanently, on a non-transitory computer readable medium such as a CD, DVD, storage device, a diskette, a tape, flash memory, physical memory, or any other computer readable storage medium. Specifically, the software instructions may correspond to computer readable program code that when executed by a processor(s), is configured to perform embodiments of the disclosure.

[0071] Further, one or more elements of the aforementioned computing system (**1600**) may be located at a remote location and connected to the other elements over a network (**1612**). Further, embodiments of the disclosure may be implemented on a distributed system having a plurality of nodes, where each portion of the disclosure may be located on a different node within the distributed system. In one embodiment of the disclosure, the node corresponds to a distinct computing device. Alternatively, the node may correspond to a computer processor with associated physical memory. The node may alternatively correspond to a computer processor or micro-core of a computer processor with shared memory and/or resources.

[0072] Although the preceding description has been described herein with reference to particular means, materials and embodiments, it is not intended to be limited to the particulars disclosed herein; rather, it extends to all functionally equivalent structures, methods and uses, such as are within the scope of the appended claims. In the claims, means-plus-function clauses are intended to cover the structures described herein as performing the recited function and not only structural equivalents, but also equivalent structures. Thus, although a nail and a screw may not be structural equivalents in that a nail employs a cylindrical surface to secure wooden parts together, whereas a screw employs a helical surface, in the environment of fastening wooden parts, a nail and a screw may be equivalent structures. It is the express intention of the applicant not to invoke 35 U.S.C. §112(f) for any limitations of any of the claims herein, except for those in which the claim expressly uses the words 'means for' together with an associated function.

What is claimed is:

1. A method comprising:

applying a correlation between the probability of stress variations in a first well and variations in drilling data obtained from the first well to drilling data obtained from one or more additional wells;

calculating a proportion of high stress and low stress contrast stages within the one or more additional wells; and

creating one or more synthetic stress profiles for various completion techniques based on the calculated proportion of high stress and low stress contrast stages within the one or more additional wells; and

using the one or more synthetic stress profiles to create a synthetic stress log for a geometric completion (GC) and an engineered completion (EC).

2. The method of claim **1**, further comprising determining a production forecast for each of the GC and the EC.

3. The method of claim **2**, further comprising flagging a subset of the one or more additional wells for EC based on the production forecast.

4. The method of claim **1**, further comprising performing GC or EC on the one or more additional wells.

5. The method of claim **1**, further comprising ranking the one or more additional wells according to one or more selected from a group consisting of production capacity, drilling quality, and dogleg severity.

6. The method of claim **1**, wherein drilling data obtained from the first well comprises one or more gamma ray logs.

7. The method of claim **1**, wherein drilling data obtained from the first well comprises one or more selected from a group consisting of weight on bit, rotations-per-minute, torque, rate of penetration, total mineralogical composition, cuttings analysis, mechanical specific energy, and thermal conductivity.

8. The method of claim **1**, wherein drilling data obtained from one or more additional wells comprises one or more gamma ray logs.

9. The method of claim **1**, wherein drilling data obtained from one or more additional wells comprises one or more selected from a group consisting of weight-on-bit, rotations-per-minute, torque, rate of penetration, total mineralogical composition, cuttings analysis, mechanical specific energy, and thermal conductivity.

10. The method of claim **1**, wherein applying the determined correlation to drilling data obtained from one or more additional wellbores comprises determining the common mineralogy for at least one of the first well and the one or more additional wells.

11. The method of claim **1**, wherein the correlation between the probability of stress variations in a first well and variations in drilling data obtained from the first well is derived from one or more selected from a group consisting of the range of minimum and maximum data values for each data set obtained from clusters within the first well; the common mineralogy for each data set obtained from clusters within the first well; and statistical processing of each data set obtained from clusters within the first well.

12. The method of claim **1**, wherein calculating a proportion of high stress and low stress contrast stages within the one or more additional wells comprises generating at least one of: a probability of high stress contrast as a function of data variation value, and a probability of low stress contrast as a function of data variation value.

13. A method comprising:

obtaining drilling data from one or more wells;

calculating a proportion of high stress and low stress contrast stages within the one or more additional wells; and

creating one or more synthetic stress profiles for various completion techniques based on the calculated proportion of high stress and low stress contrast stages within the one or more wells.

14. The method of claim **13**, further comprising using the one or more synthetic stress profiles to create a synthetic stress log for a geometric completion (GC) and an engineered completion (EC).

15. The method of claim **14**, further comprising determining a production forecast for each of the GC and the EC.

16. The method of claim **15**, further comprising flagging a subset of the one or more additional wells for EC based on the production forecast.

17. The method of claim **14**, further comprising performing GC or EC on the one or more additional wells.

18. The method of claim **13**, further comprising ranking the one or more wells according to one or more selected from a group consisting of production capacity, drilling quality, and dogleg severity.

19. The method of claim **13**, wherein drilling data obtained from the one or more wells comprises one or more selected from a group consisting of weight-on-bit, rotations-per-minute, torque, rate of penetration, total mineralogical composition, cuttings analysis, mechanical specific energy, and thermal conductivity.

20. The method of claim **13**, wherein obtaining drilling data from one or more wells comprises determining the common mineralogy for the one or more wells.

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